NATIONAL BUREAU OF STANDARDS REPORT

7161

EVALUATION OF RESISTANCE STRAIN GAGES
AT ELEVATED TEMPERATURES

Progress Report No. 12

by

J. T. Trumbo, C. H. Melton and R. L. Bloss

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Engineering Mechanics Section
Division of Mechanics

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NATIONAL BUREAU OF STANDARDS

FOREWORD

In recent years the use of structures at elevated temperatures has increased greatly. If the safe design and efficient use of structural materials are to be assured, a knowledge of the properties of materials and of structural configurations is essential. In determining these properties, the measurement of strains and deformations is important. Strain gages to measure these quantities must be capable of operating satisfactorily over a wide temperature range.

In order to determine the characteristics of strain gages which are available for use at elevated temperatures, the Department of the Navy and the Department of the Air Force have sponsored a program for the evaluation of these gages. This report is one of a series giving the results of these evaluation tests.

There is a continuing effort on the part of manufacturers and research organizations to develop improved strain gages for use at elevated temperatures. Therefore the results given in this report would not necessarily show the performance of similar gages which may differ in characteristics due to differences in materials, treatments, or methods of fabrication.

L. K. Irwin
Chief, Engineering Mechanics Section

B. L. Wilson
Chief, Mechanics Division

CONTENTS

Evaluation of Resistance Strain Gages at Elevated Temperatures

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J. T. Trumbo, C. H. Melton and R. L. Bloss

SYNOPSIS

Type FNH-25-12B resistance strain gages, manufactured by the Baldwin-Lima-Hamilton Corporation, were evaluated at elevated temperatures. The factors investigated included (1) gage factor at about 75° F, (2) variation of gage factor with increasing temperature, (3) response when subjected to large strains, (4) change of resistance with time at various constant temperatures, (5) change of resistance with temperature, (6) response when subjected to high heating rates, and (7) resistance between the gage and the base material.

The results of these tests indicate that the gage factor at 75° F is within the manufacturer's stated range; that the gage factor at 1000° F is about 90 percent of the room temperature value; that the gages are able to sustain strains of 0.004 at 75° F and of 0.002 at 600° F; that the temperature coefficient of resistance of the gages installed on type 302 stainless steel is high, positive, and nearly constant between 75° and 800° F but changes rapidly and becomes very high between 800° and 1200° F; and that the gage response is repeatable under a given transient heating condition.

1. INTRODUCTION

In the continuing evaluation of resistance strain gages designed for use at elevated temperatures, gages manufactured by the Baldwin-Lima-Hamilton Corporation were subjected to tests. The gages tested were type FNH-25-12B. These gages were subjected to tests to determine the following characteristics:

(1) Gage factor at about 75° F,

(2) Variation of gage factor with increasing temperature,

(3) Response of the gages when subjected to large strains,

(4) Relative change of resistance with time at constant temperatures,

(5) Resistance-temperature relationship,

(6) Behavior when subjected to transient heating, and

(7) Resistance between the gage and the test strip.

The results of previous evaluations of other gage types are given in references 1 through 10.

2. GAGE DESCRIPTION

The gages which are reported on herein are type FNH-25-12B purchased from the Baldwin-Lima-Hamilton Corporation. As shown in figure 1 the active element is an etched foil grid of Nichrome V with extended end tabs and a strippable backing. The gages are described in the manufacturer's bulletin No. 4320.

Allen P-1 cement, also purchased from the Baldwin-Lima-Hamilton Corporation, was used to attach the gages to stainless steel test strips. Of 34 gages installed (some used for purposes other than those reported), more than half had cracks in the cement covering the grids. These cracks ranged in size from those that could not be seen without magnification to those easily seen by the unaided eye. The gage element did not appear to be exposed by these cracks. The gage installation procedure was that given in the manufacturer's installation instructions revised as of December 18, 1958. The installation procedures are described in the appendix to this report.

3. TEST EQUIPMENT AND METHODS

The equipment and methods used for the evaluation tests are described in references 5, 8, 11 and 12.

4. RESULTS

The number of gages subjected to the various tests is given in table 1. The voltages applied to the test circuits are shown in table 2. The results of the evaluations are given in tables 3 and 4 and figures 2 through 28.

4.1 Gage Factor

Gage factor values were obtained at about 75° F from four gages for a maximum strain of about 0.001 in tension and compression. These values are given in table 3 where

K_u = gage factor for increasing load,

K_d = gage factor for decreasing load, and

$\overline{K}$ = average of K_u and K_d.

All gage factor values at 75° F agree with the value furnished by the manufacturer, 2.2 ± 0.1. Gages 2.3-A_1 and A_3 were tested in tension before being tested in compression. Gages 2.3-A_2 and A_4 were tested in compression before being tested in tension. The testing of gage 2.3-A_2 was interrupted during the third compression loading cycle by an equipment failure. A fourth test run with compression loading was subsequently carried out with this gage.

The gage factor values are also shown in figure 2. Differences between the experimentally determined values and the manufacturer's nominal value, expressed as a percent of the nominal value, are plotted. Values for tensile loading are plotted on the abscissa; and values for compressive loading are plotted on the ordinate. The differences between the values determined during the tests and the manufacturer's nominal value are shown by the departure of the points from the origin. Departure from the diagonal line indicates a difference between gage factor values for tensile and compressive loading. This figure shows that all values were within the manufacturer's tolerance (about ± 4.5 percent), that gage to gage variation is greater than run to run variation for one gage, and that the gage factor is slightly higher for tensile loading than for compressive loading.

Figures 3 through 5 show the departure from linearity of the gage response and the zero shift for the first and third loading cycles to about 1000 microinches per inch strain in tension and compression. Open symbols connected with a dashed line indicate increasing load and solid symbols connected with a solid line are for decreasing load. The values plotted have been corrected for temperature fluctuations. Examination of the data and figures indicates that, except for run one of gage 2.3-A_1 in the tension direction, the gage response to strain is nearly linear and that strains computed using the nominal gage factor value, 2.2, did not differ from actual values by more than 20 microinches per inch.

4.2 Variation of Gage Factor with Temperature

The variation of gage factor with increasing temperature is shown in figures 6 through 9. Each curve of figures 6 through 8 represents the average change of gage factor of two gages which are mounted on opposite sides of a beam and connected in adjacent arms of a bridge circuit. Figure 9 shows the average of all runs for each set of two gages and the extreme values of all runs of all gage sets. These figures indicate good repeatability from gage to gage as well as among tests of the same gage. The gage factor was found to decrease about 9 percent in a nearly linear manner as the temperature increased from 75° to 1000° F.

4.3 High Strains

Five gages were subjected to tensile strains greater than those used for the determination of gage factor. The results are shown in figures 10 and 11. In order to determine the indicated strain of the gage $\epsilon_{Ind} = \frac{1}{K} \frac{\Delta R}{R}$, the value of K at 75° F was taken as the grand average of the values obtained in the room temperature gage factor tests. For the high strain tests at 600° F, the room temperature gage factor value was adjusted by the average amount found during the variation of gage factor with temperature tests.

At room temperature both gages failed at an actual strain of about 0.004. At 600° F gage failure or large errors occurred at strains of 0.002 to 0.004. The initial slope of the curves for tests at 600° F indicated a gage factor about 5 percent higher than the value calculated from results of the gage factor and variation of gage factor tests. This difference cannot be explained from the results of tests covered by this report. Gage failure was evidenced by a rapid increase in gage resistance for small strain increments or an open circuit within the gage. In all instances the bond between the cement and test bar remained intact.

4.4 Drift

Records of relative change of resistance with time for single gages at several test temperatures are shown in figures 12 through 21. These results were obtained after heating the gage installation at about 10° F per second from room temperature or the next lower test temperature. Recording was started 1 minute after the desired test temperature was reached. The second test run was made after the gages had been tested once at each test temperature up to 1500° F. The temperature fluctuations

during the 30 minute recording periods were not greater than the values shown on the figures. Although temperature variations appear to be one of the factors affecting the gage circuit output, no attempt was made to correct the data for temperature fluctuations. It should be noted that the higher drift values at 700°, 800°, and 900° F required the use of different scales than those used in presenting the results obtained at other temperatures. During the first test series, the drift rate during the first 5 minutes was generally greater than 250 parts per million resistance change per minute at temperatures above 600° F and below 1200° F. At the end of the first series two of the gages were unbonded due to corrosion of the stainless steel. Results obtained from a second series of tests of the gage that remained bonded, 2.3-D_4, indicate that the drift is strongly affected by gage history. Drifts found during this second series were generally significantly less than during the first series except at 1000° F where the drifts for the two runs were approximately of the same magnitude but of opposite direction (figure 16).

4.5 Temperature Sensitivity

Temperature coefficient values, relative change of resistance per unit temperature change, for two gages mounted on type 302 stainless steel are shown in figure 22. Each point was determined as the slope of a line drawn tangent to a curve of relative change of gage resistance versus temperature recorded while the test strip temperature was increased at about 10° F per second. Since the values obtained from the second and third test runs on one gage did not differ by as much as 20 ppm per °F, the averages of these runs are shown. The curves show some difference between gages and considerable dependence upon gage history in the temperature range between 800° and 1200° F.

Temperature coefficient values were obtained from curves recorded at a sensitivity sufficiently high to require rebalancing the bridge circuit circuit several times during the test. Because of the resulting discontinuities in the recorded curves, an indication of the total change of gage resistance with temperature was not directly obtainable. Therefore the curves of figure 23 were obtained by mechanical integration of the temperature coefficient curves in order to show the change of gage resistance with increasing temperature.

4.6 Transient Heating

The results of tests in which the temperature of the test strip to which the gage was attached changed at about 50° F per second are shown in figures 24 through 27. The gages were mounted on test strips of type 302 stainless steel. Figures 24 and 25 show the response of gages

2.3-R_1 and 2.3-R_2 when subjected to three series of transient heating cycles. Each heating series consisted of five heating cycles from room temperature to a maximum temperature and back to room temperature. The maximum temperatures were about 600°, 800°, 1000°, 1200°, and 1500° F (temperature changes of about 500° to 1400° F). Gage 2.3-R_1 was subjected to one cycle of heating to 1000° F before the results shown were obtained. The curves for the second and third tests could not be separated on the scale used to show the results.

Examination of the figures shows that the gage response is nearly linear up to about 1000° F; the gage response is affected by history; and the variation of response from gage to gage is comparable to the variation between the first run and subsequent runs of the same gage.

4.7 Leakage Resistance

The average resistances between the gages and the test strips are shown in figure 28. The resistance measurements were made with a Triplett vacuum tube voltmeter, Model 650. The common terminal of the instrument was connected to the test strip. The readings were taken within a few minutes after the test strip had reached the test temperature. Resistance between the gage and test strip decreased rapidly with increasing temperature. The values shown can be considered as only a qualitative indication of the insulating property of the cement since ceramic cements would not be expected to follow Ohm's law.[13]

4.8 Gages Destroyed

During the installation and testing of these gages, eight gages were damaged, destroyed, or the intended information was not obtained from them. The number of gages lost and the reasons for the loss, if known, are shown in table 4.

5. CONCLUSIONS

For gages of this type, the data obtained from the evaluation tests covered by this report indicate that:

(1) Gage factor values determined at strains up to 0.001 at 75° F agree with the manufacturer's value of 2.2 ± 0.1. The gage resistance is a nearly linear function of strain over this strain range.

(2) The gage factor decreases approximately 9 percent as the temperature increases from about 75° to 1000° F. This decrease is nearly linear with temperature.

(3) At room temperature, these gages can sustain strain of about 0.004 without failure. At 600° F, the strain range is reduced to 0.002 to 0.003.

(4) The drift behavior is repeatable from gage to gage and is strongly affected by gage history.

(5) The temperature coefficient of the gage is nearly constant and repeatable from 75° to about 800° F. Between 800° and 1200° F the temperature sensitivity is strongly affected by gage history. In the range of 800° to 1200° F the high and rapidly changing temperature sensitivity could introduce large and uncertain errors in indicated strain. After exposure to 1500° F the temperature coefficient in the 800° to 1200° F range is greatly reduced and repeatable.

(6) The response of the gage when subjected to transient heating conditions becomes repeatable after one heating cycle to 1500° F. Variation of response from gage to gage is of the same magnitude as the variation between the first heating cycle to 1500° F and subsequent tests.

(7) The resistance between the gage and test strip decreases rapidly with increasing temperature. This resistance at temperatures below 1200°F is significantly increased by heating the gage installation to 1500° F.

Washington, D. C.
May 1961

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(12) R. L. Bloss, "Evaluation of Resistance Strain Gages at Elevated Temperatures," Materials Research and Standards, Vol. 1, No. 1, p. 9 (1961).

(13) J. W. Pitts, E. Buzzard, and D. G. Moore,"Resistance Measurement of Ceramic-Type Strain-Gage Cements, Symposium on Elevated Temperature Strain Gages," ASTM Special Technical Publication No. 230, pp 67-75.

APPENDIX

The type FNH-25-12B gages tested for this report were installed on stainless steel (type 302 and 303) in the following manner:

A. Cement Preparation

1. Allen P-1 cement, procured from Baldwin-Lima-Hamilton Corp., was mixed in the proportion of two parts powder to one part liquid by volume.

2. A few hours were allowed to elapse before the cement was used.

B. Surface Preparation

1. The test specimens were cleaned with toluol and then acetone to remove petroleum products.

2. The surface was roughened by lightly sandblasting and recleaned with acetone.

3. The surface was scrubbed with a gauze pad saturated with Allen P-1 cement. Excess cement was wiped off with a clean gauze pad.

4. A thin coating of cement, about 0.001 inch thick, was applied to an area larger than would be occupied by the gage. The precoat was air dried for 30 minutes and then cured for one hour at 220° F followed by one hour at 600° F.

C. Gage Preparation

1. The backing material was stripped from the heavy end tabs for approximately half their length and the free plastic material was removed with scissors.

2. A one-inch piece of Nichrome V ribbon was formed into a "fish mouth" by folding one end of the ribbon back on itself, welding the free end to itself to form a small loop, and cutting the end of the loop. A "fish mouth" thus formed was sandwiched over each gage tab and spotwelded to it.

3. The backing material was stripped from the grid end of the gage for about one fourth of the grid length.

4. The gage bonding surface was cleaned of contamination by wetting the exposed surface of the gage and tabs with cement and stroking the grid with the index finger.

C. Gage Installation

1. The surface of the precoat was prewetted by applying a heavy coat of cement and then removing the excess with a piece of gauze.

2. A thin coat of cement was then applied to the precoat and the gage placed into the cement with the foil side down.

3. The prestripped backing from the grid end was folded back and the exposed grid covered with a thin coat of cement which was then covered with the backing and the gage firmly pressed into the cement.

4. A thin coat of cement was brushed over the exposed tabs and half of the ribbon lead length. The installation was then air dried until the cement did not adhere to the gage side of the backing material.

5. The backing material was stripped from the lead end toward the bottom of the grid exposing approximately one quarter of the grid and a thin coat of cement was applied. The backing material was replaced and the gage pressed into the cement.

6. The tabs and half the ribbon lead length were covered with a second thin coat of cement and then air dried.

7. Starting at the grid end the backing material was removed from the entire gage and a thin coat of cement applied to the exposed grid area and a heavier coat over the tabs and leads.

8. The first coat was semi-cured for 30 minutes at approximately 200° F and a second cover coat applied after the installation had cooled.

9. The gage installation was given a final cure by slowly raising the temperature to 200° F, holding this temperature for two hours, raising the temperature to 600° F at a rate of approximately 200° F per hour, and curing at 600° F for one hour. The installation was then cooled in the furnace.

Table 1 - Number of Gages Subjected to Tests

Type of Test	No. of gages tested
Gage factor	4
Variation of gage factor with temperature	6
High strain	5
Drift	3
Temperature sensitivity	2
Transient heating	2
Leakage resistance	3*

*Leakage resistance was determined during the drift tests.

Table 2 - Voltage Applied to Test Circuits

Type of Test	Approximate voltage
Gage factor	3
Variation of gage factor with temperature	6
High strain	5*
Drift	8
Temperature sensitivity	5
Transient heating	8
Leakage resistance	1

*1000 cps. All other power was dc.

Table 3 - Gage Factor Values at About 75° F

Gage No.	Run No.	Gage Factor Values					
		Tension			Compression		
		K_u	K_d	$\overline{K}$	K_u	K_d	$\overline{K}$
$2.3\text{-}A_1$	1	2.111	2.251	2.181	2.216	2.187	2.201
	2	2.192	2.216	2.204	2.199	2.198	2.198
	3	2.203	2.200	2.202	2.200	2.192	2.196
	Average	2.169	2.222	2.196	2.205	2.192	2.198
$2.3\text{-}A_2$	1	2.222	2.221	2.222	2.201	2.195	2.198
	2	2.210	2.223	2.217	2.217	2.179	2.198
	3	2.220	2.216	2.218	2.197	-	-
	4				2.219	2.182	2.201
	Average	2.217	2.220	2.219	2.208	2.185	2.199
$2.3\text{-}A_3$	1	2.218	2.235	2.227	2.221	2.210	2.216
	2	2.218	2.231	2.224	2.214	2.207	2.210
	3	2.225	2.228	2.227	2.217	2.209	2.213
	Average	2.220	2.231	2.226	2.217	2.209	2.213
$2.3\text{-}A_4$	1	2.240	2.239	2.240	2.210	2.234	2.222
	2	2.237	2.244	2.240	2.223	2.235	2.229
	3	2.239	2.238	2.239	2.224	2.234	2.229
	Average	2.239	2.240	2.240	2.219	2.234	2.227

Table 4 - Gages Lost Before Completion of Tests

No. of gages lost	Remarks
1	Gage grid was damaged in welding lead ribbons to tabs.
1	Grid loop was damaged while applying cement.
2	Open circuit was found in gage upon completion of installation.
2	Bond between the cement and the stainless steel test strip failed upon exposure to 1500° F.
2	Gage was damaged in handling after completion of installation.

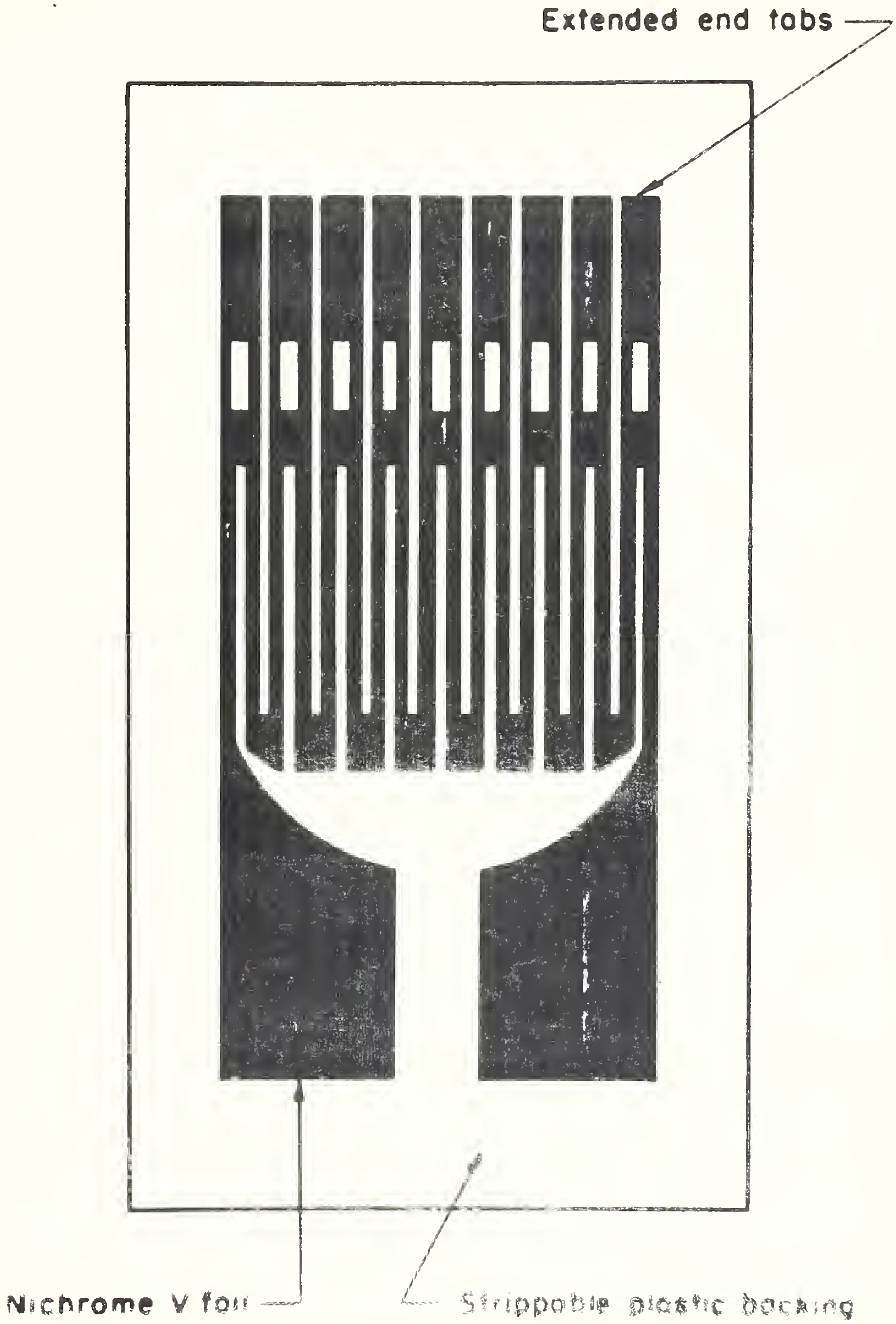


Fig. 1 Gage configuration.

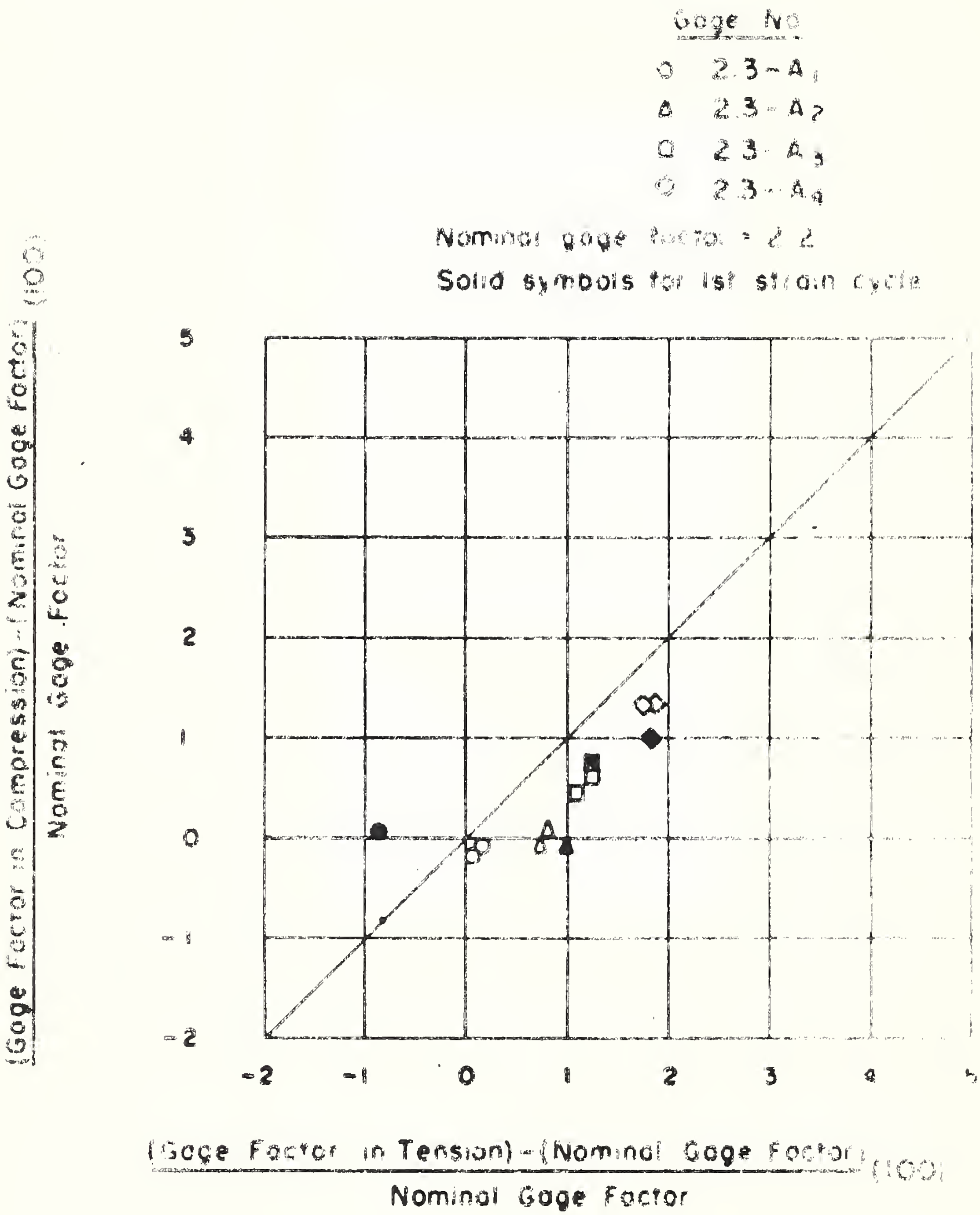


Fig. 2 Gage factor deviation at 75°F

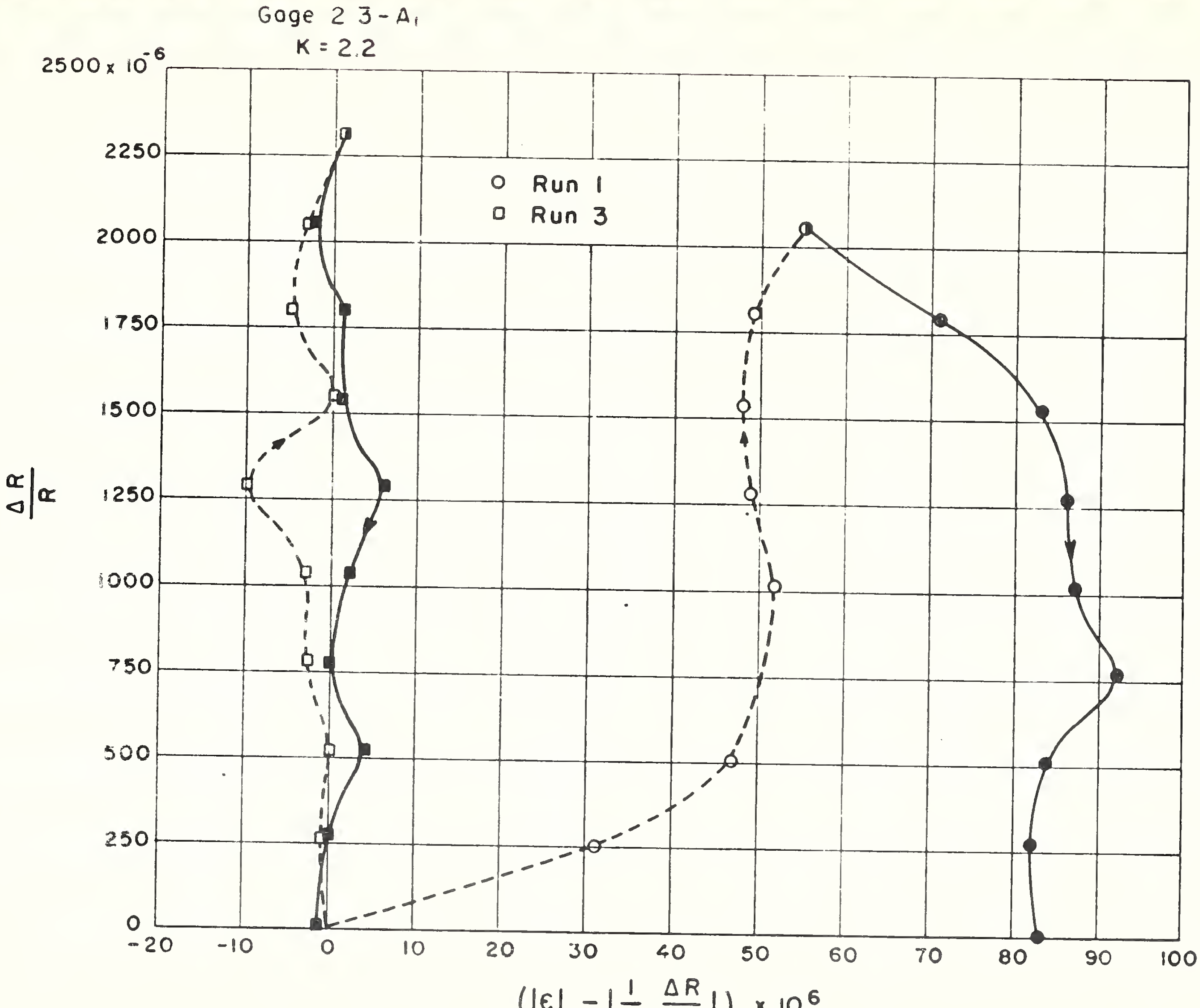


Fig. 3 Strain deviation for tension loading

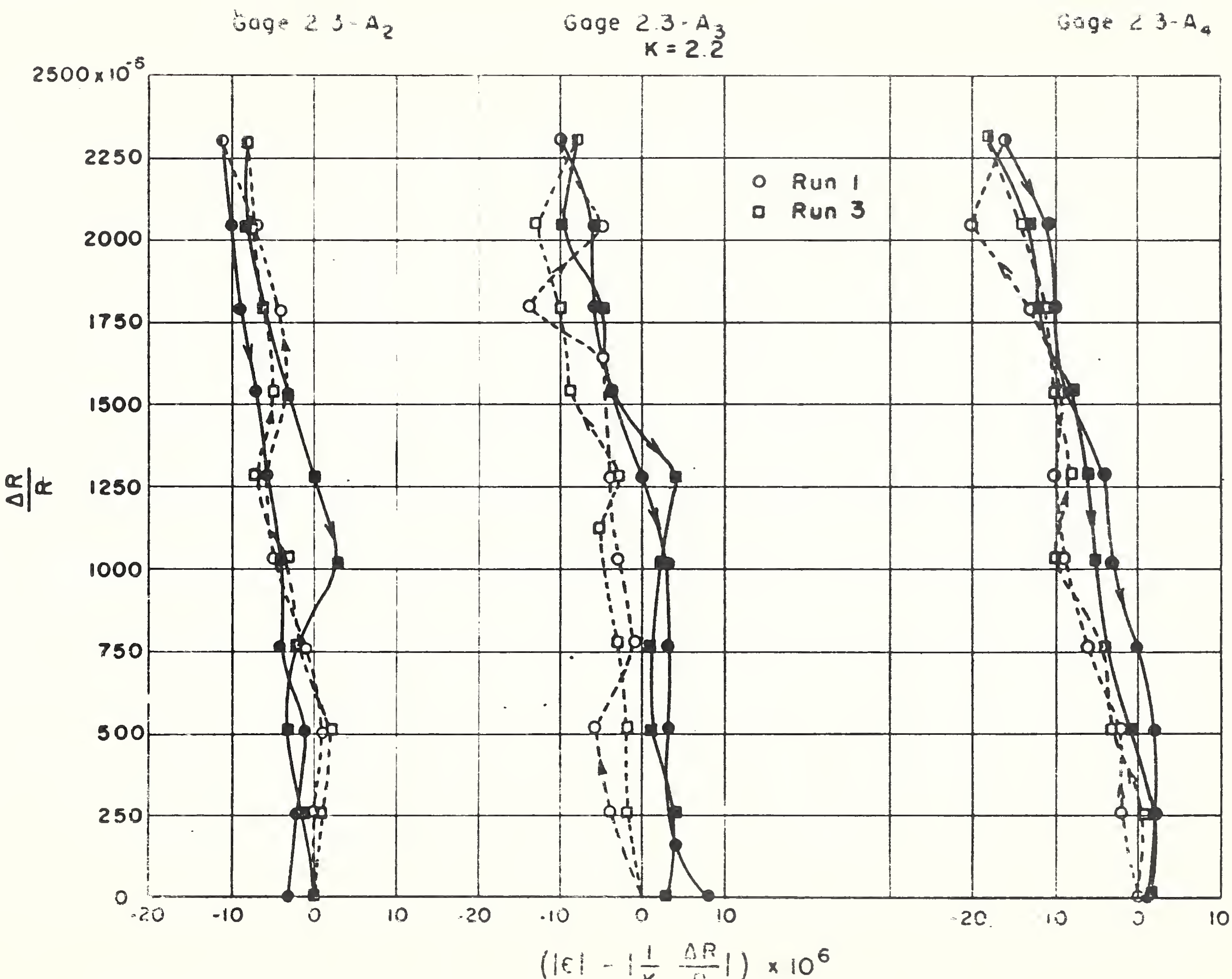


Fig 4 Strain deviation for tension loading

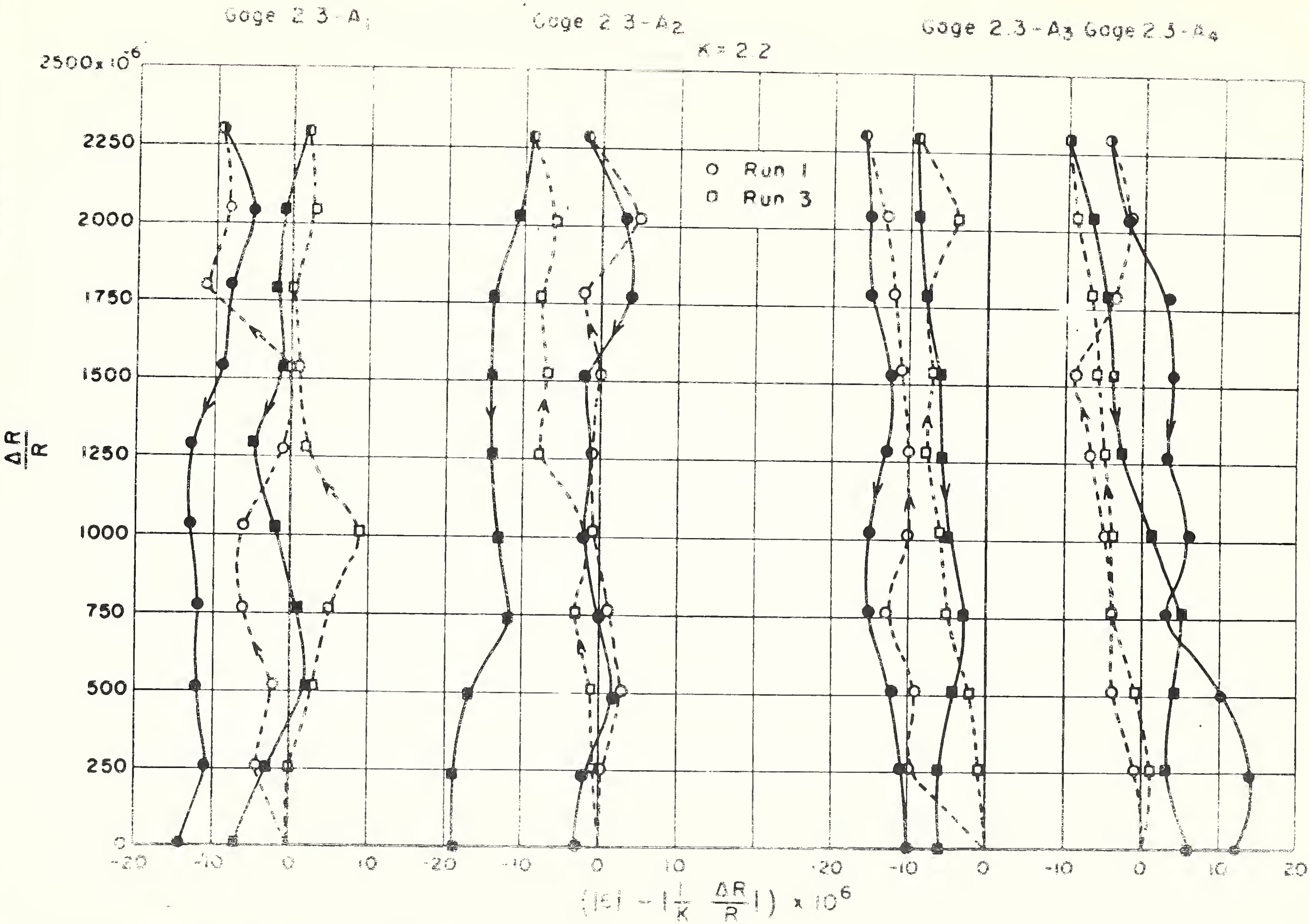


Fig. 5 Strain deviation for compression loading

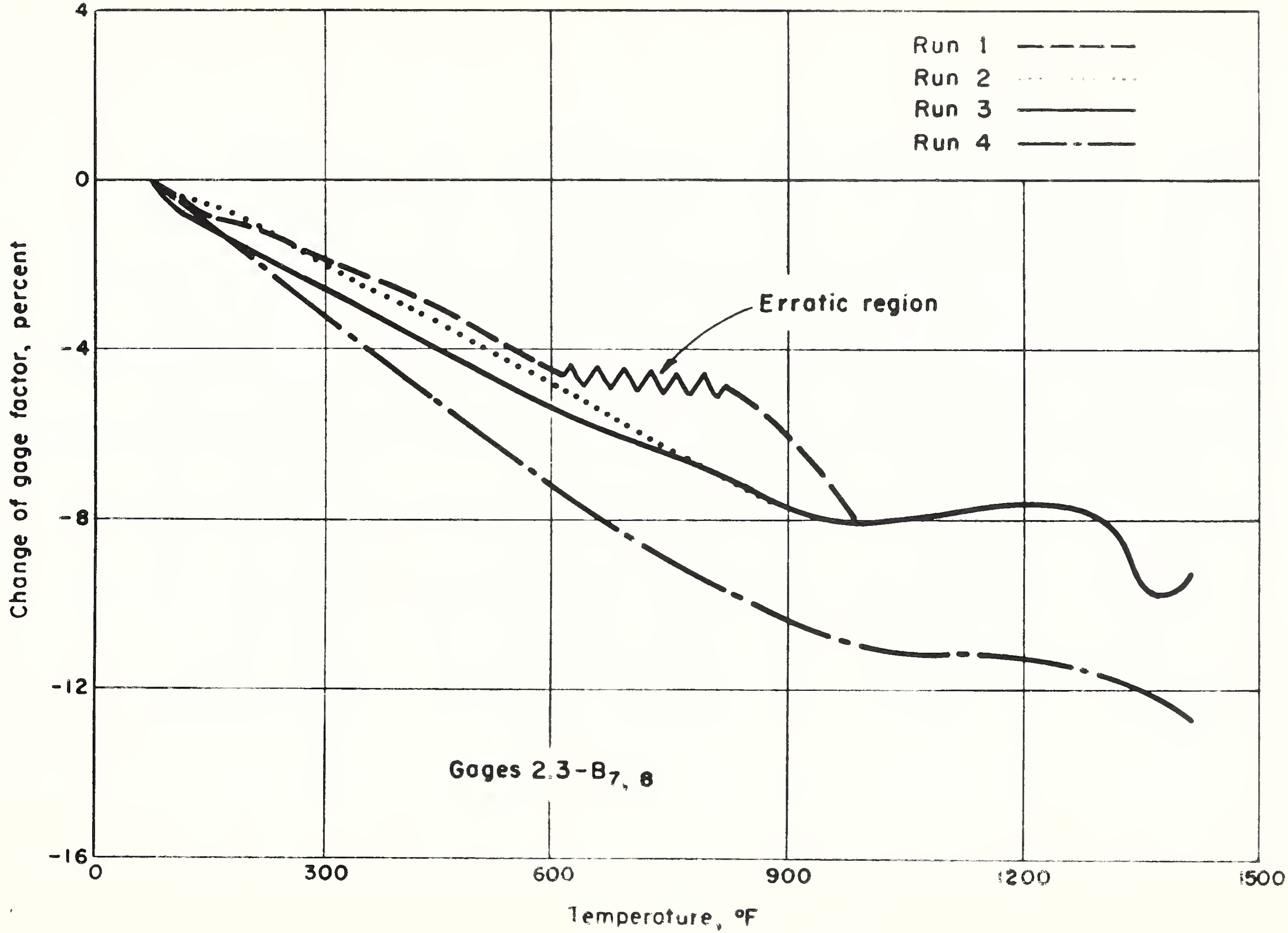


Fig. 6 Variation of gage factor with temperature

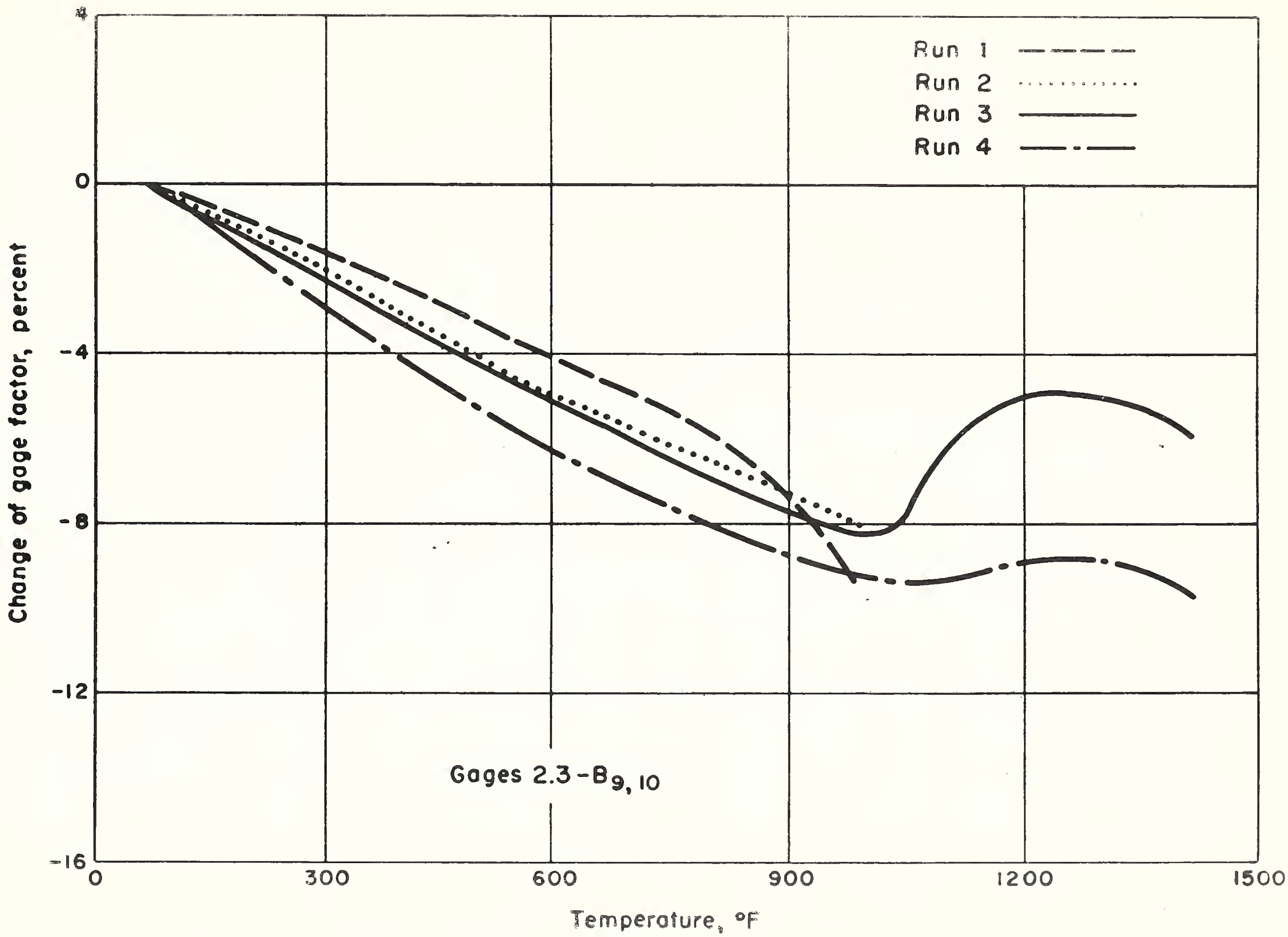


Fig 7   Variation of gage factor with temperature

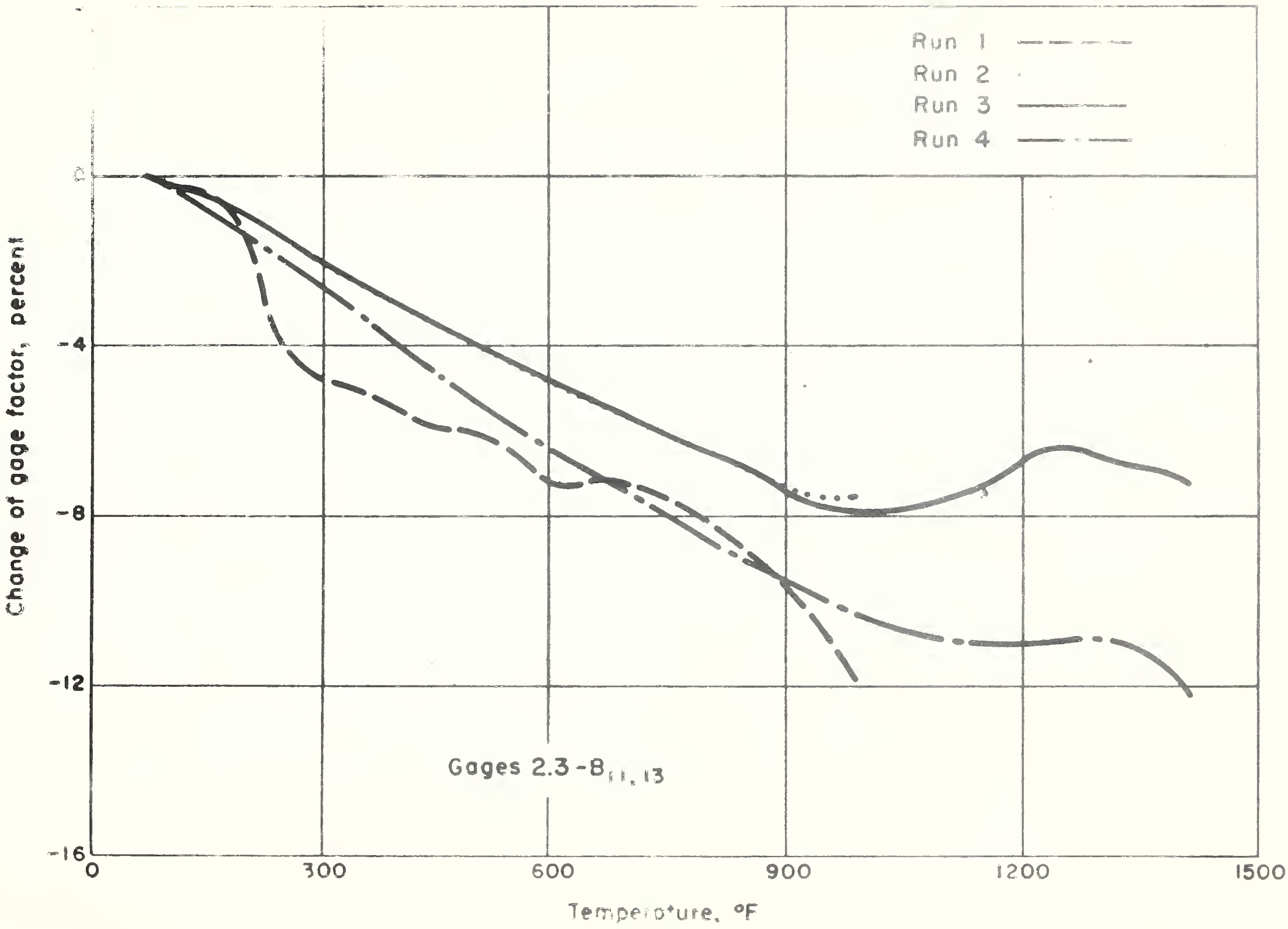


Fig. 8 Variation of gage factor with temperature

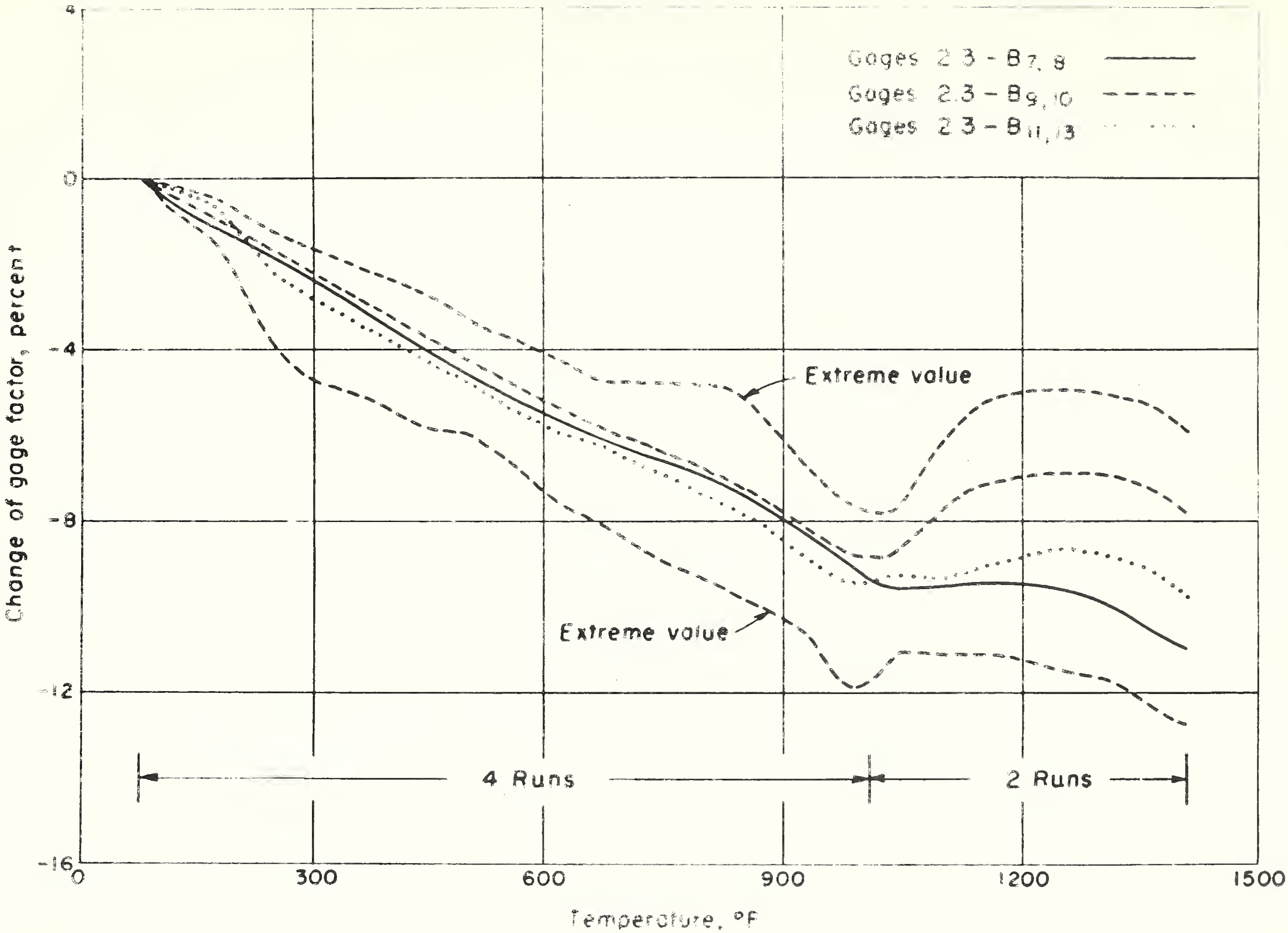


Fig 9 Variation of gage factor with temperature — average values

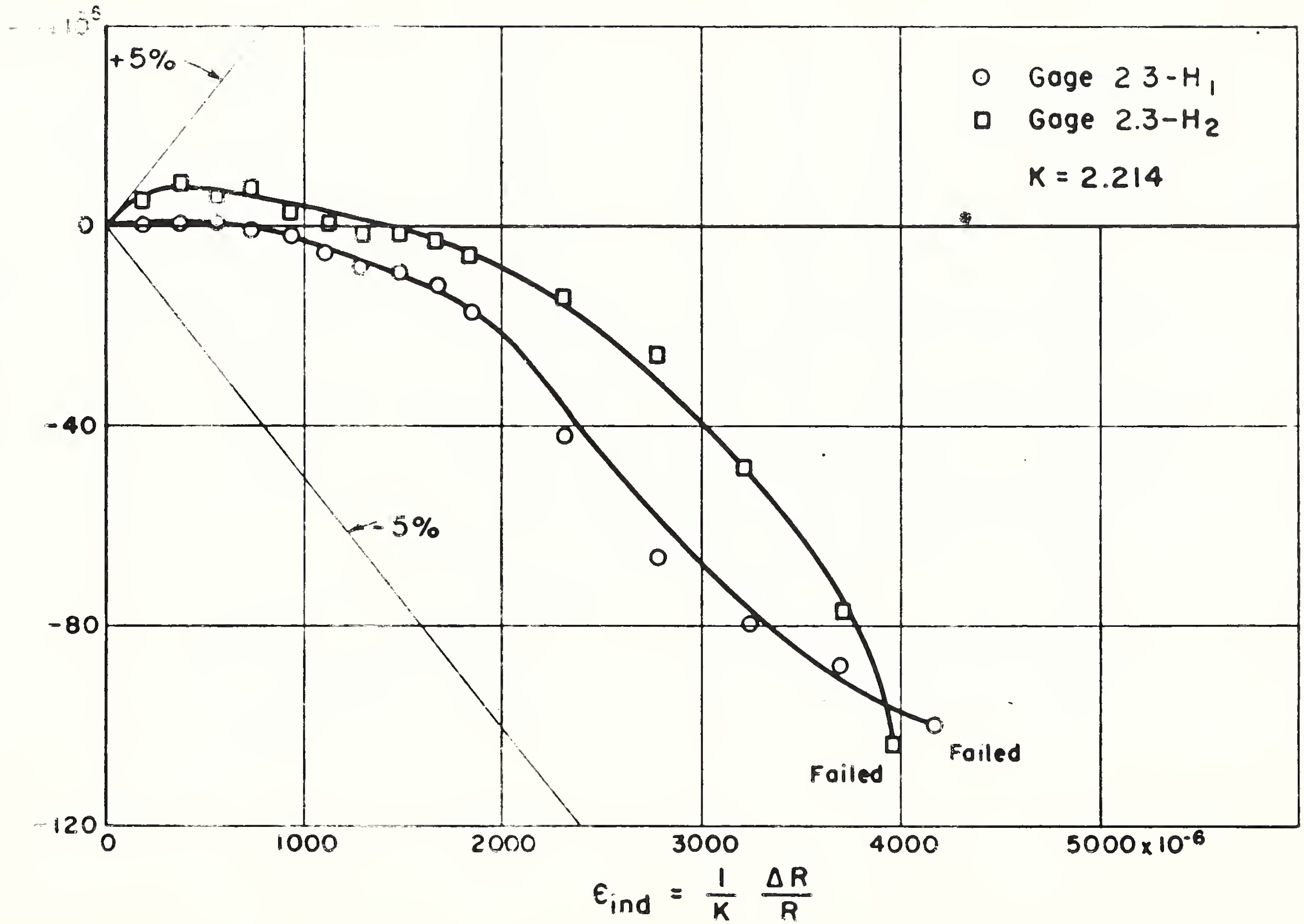


Fig. 10 Gage behavior at high strains at 75° F

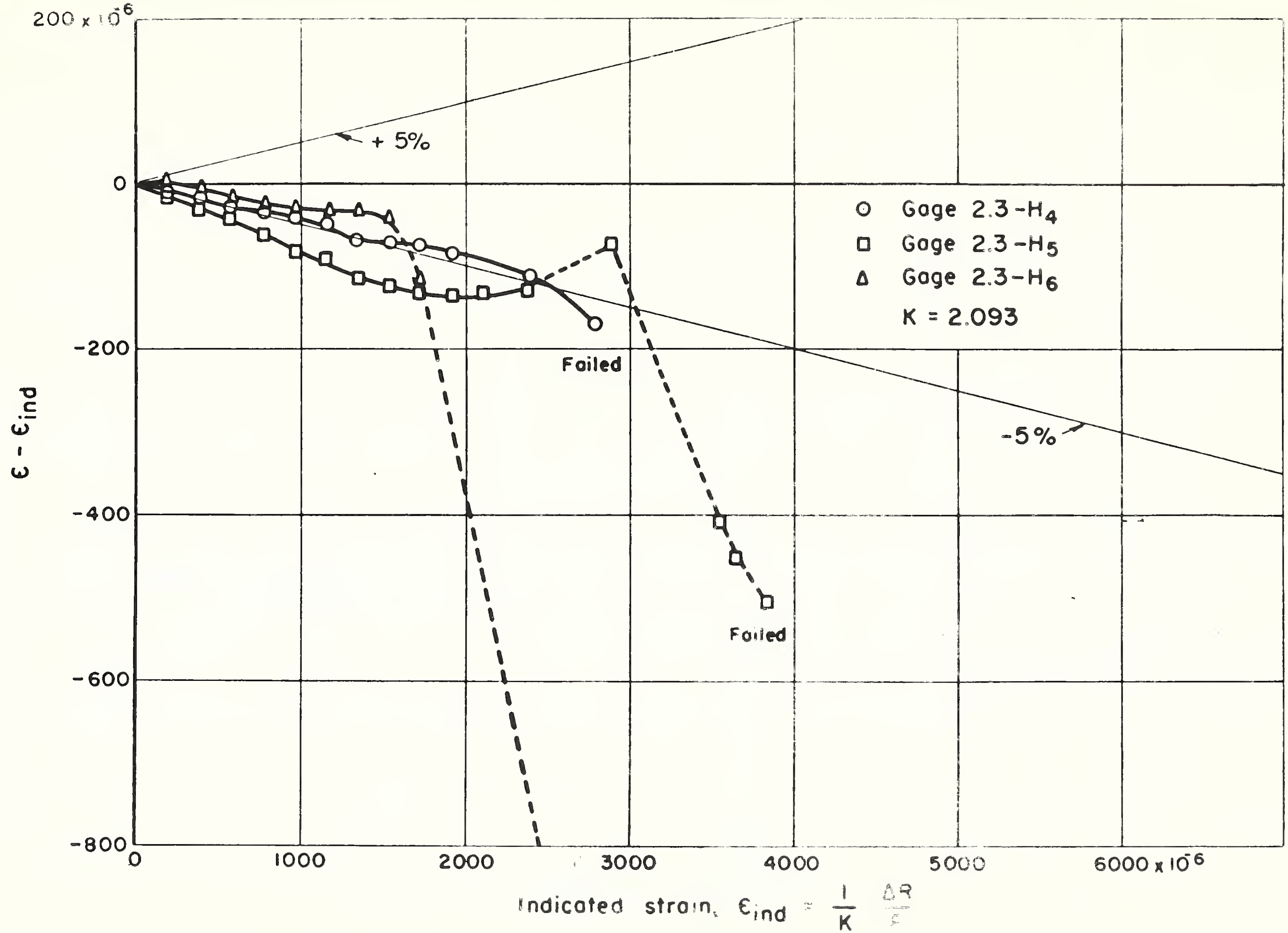


Fig. 11 Gage behavior at high strains at 600°F

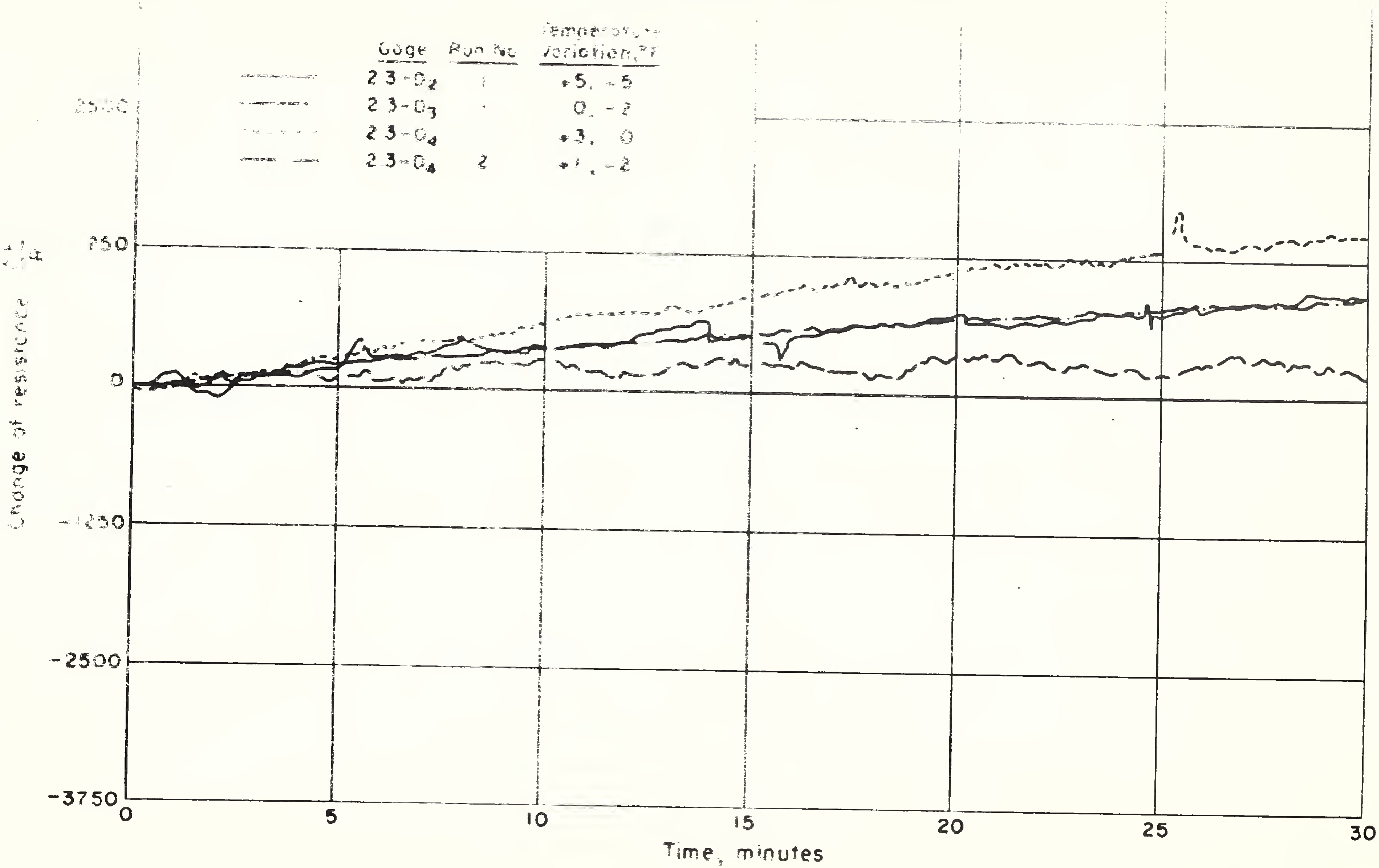


Fig 12 Drift behavior at 600°F

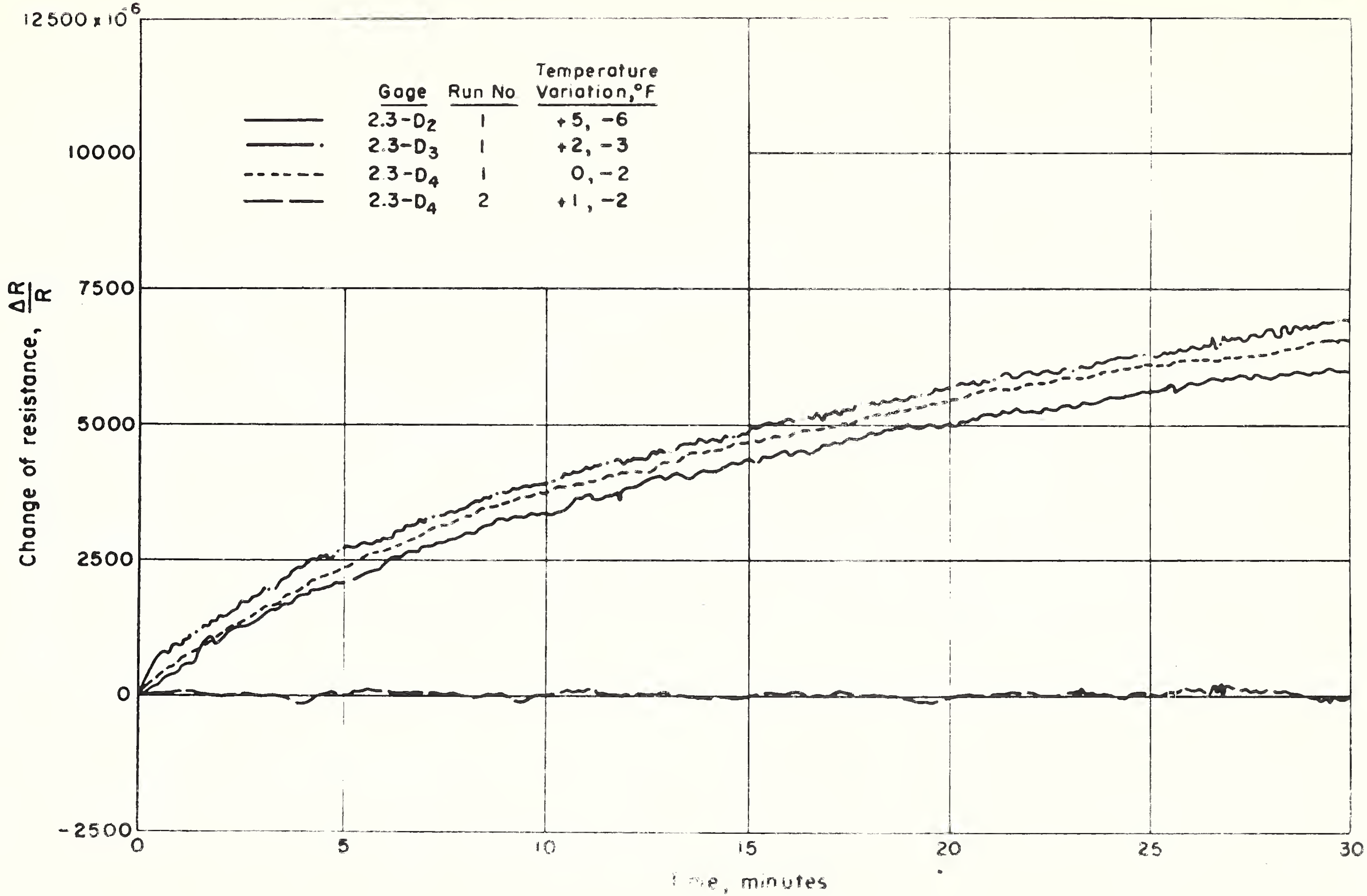


Fig. 13 Drift behavior at 700°F

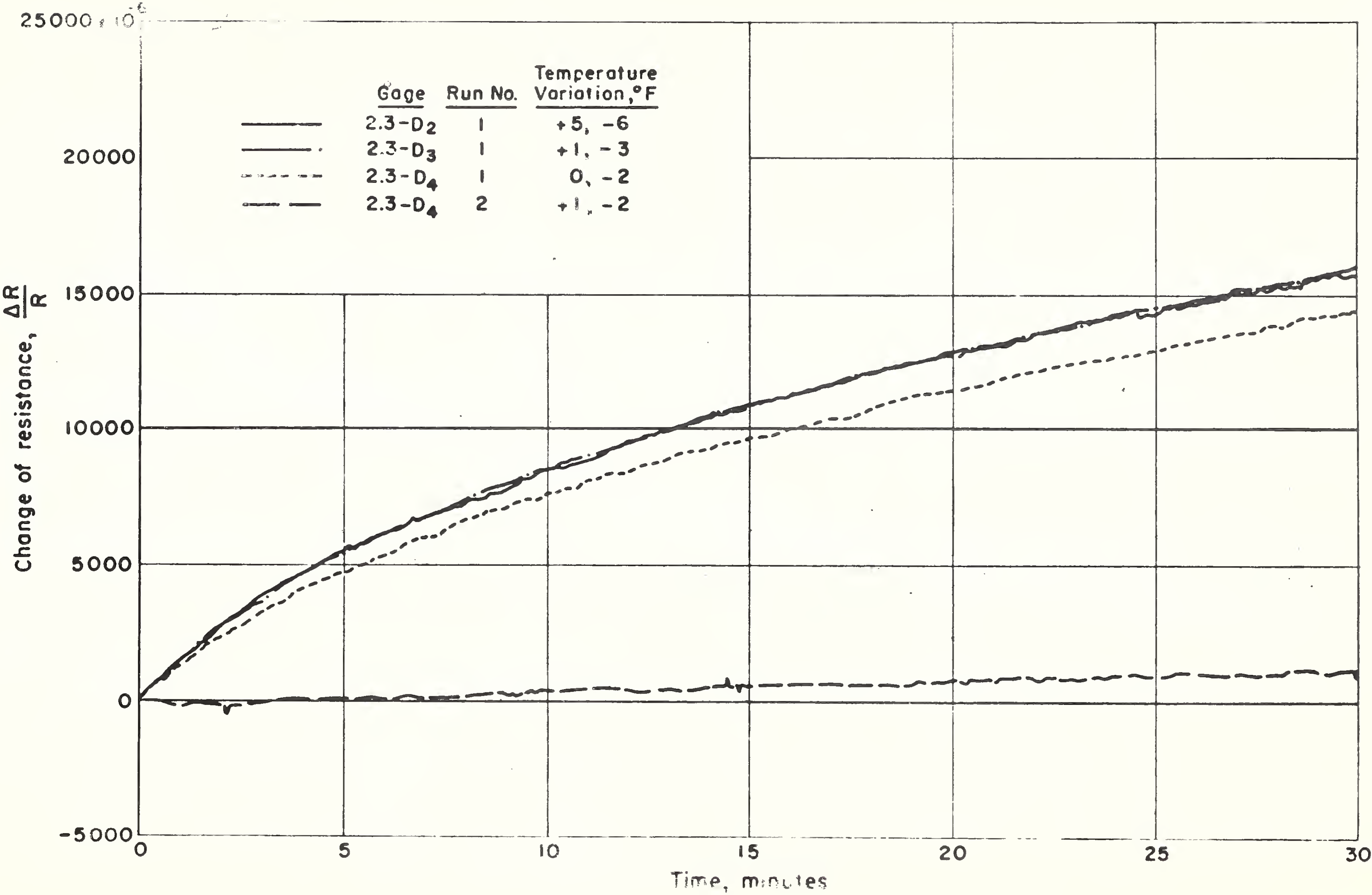


Fig. 14 Drift behavior at 800 °F

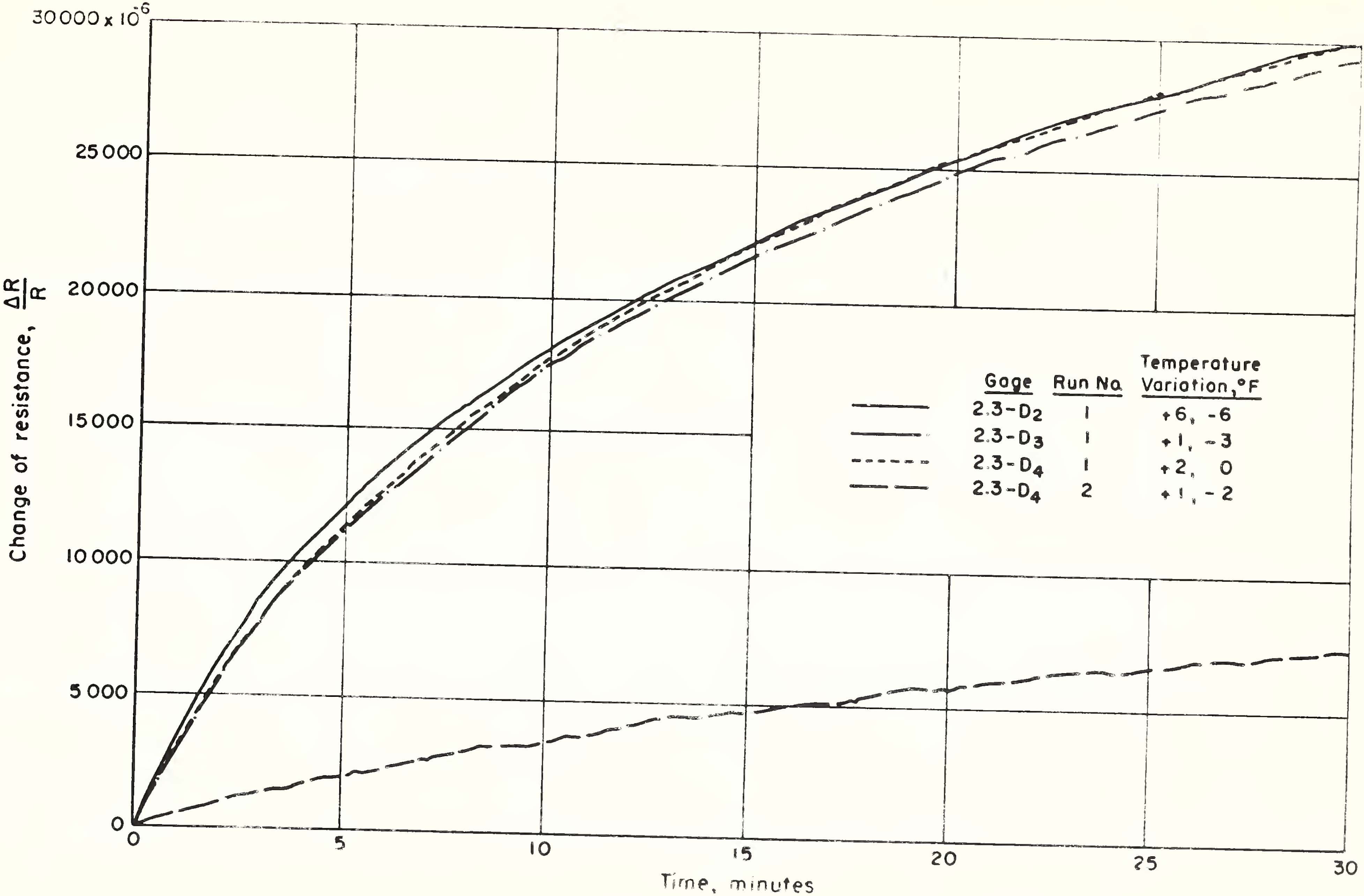


Fig 15 Drift behavior at 900°F

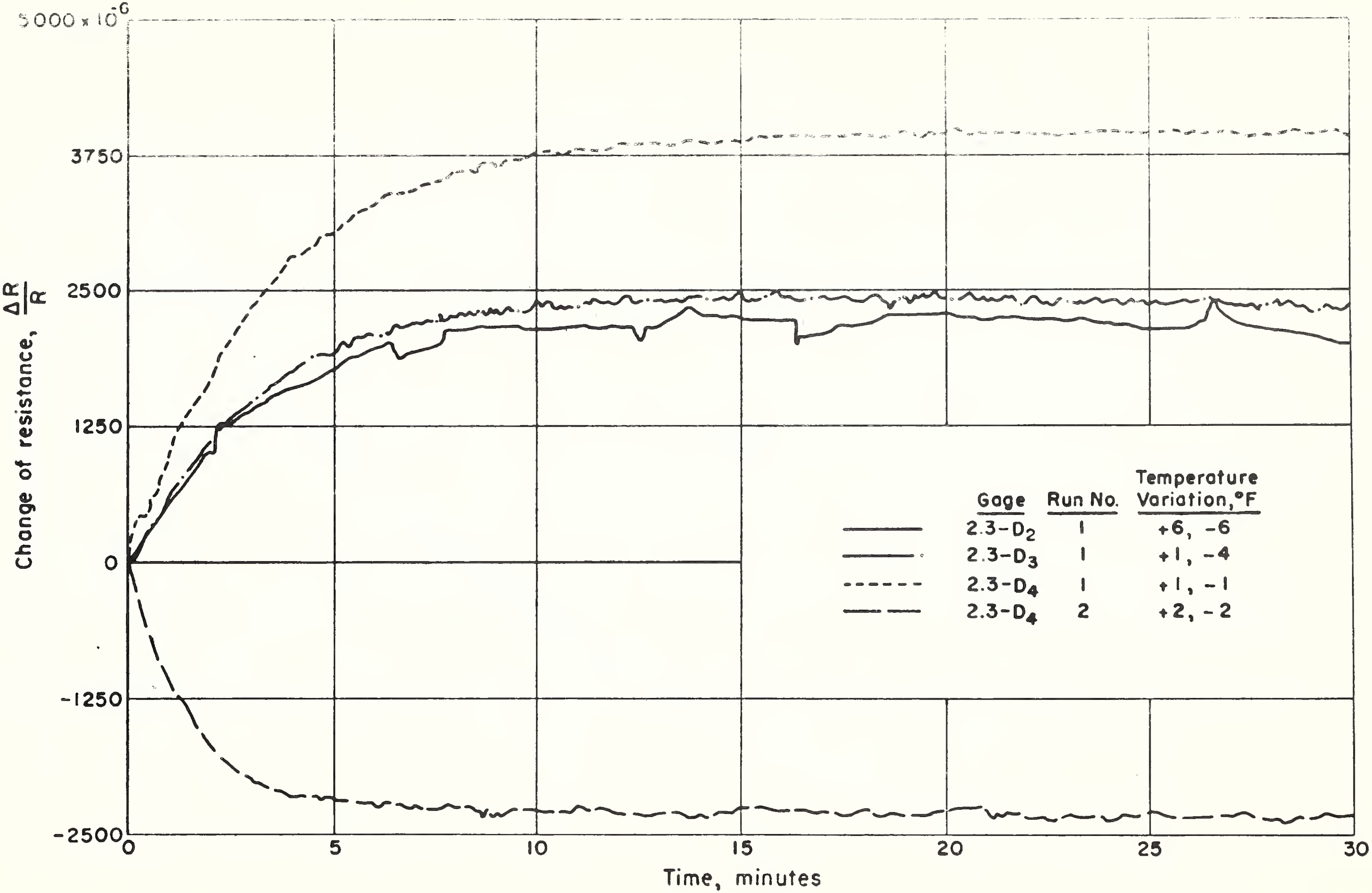


Fig. 16 Drift behavior at 1000° F

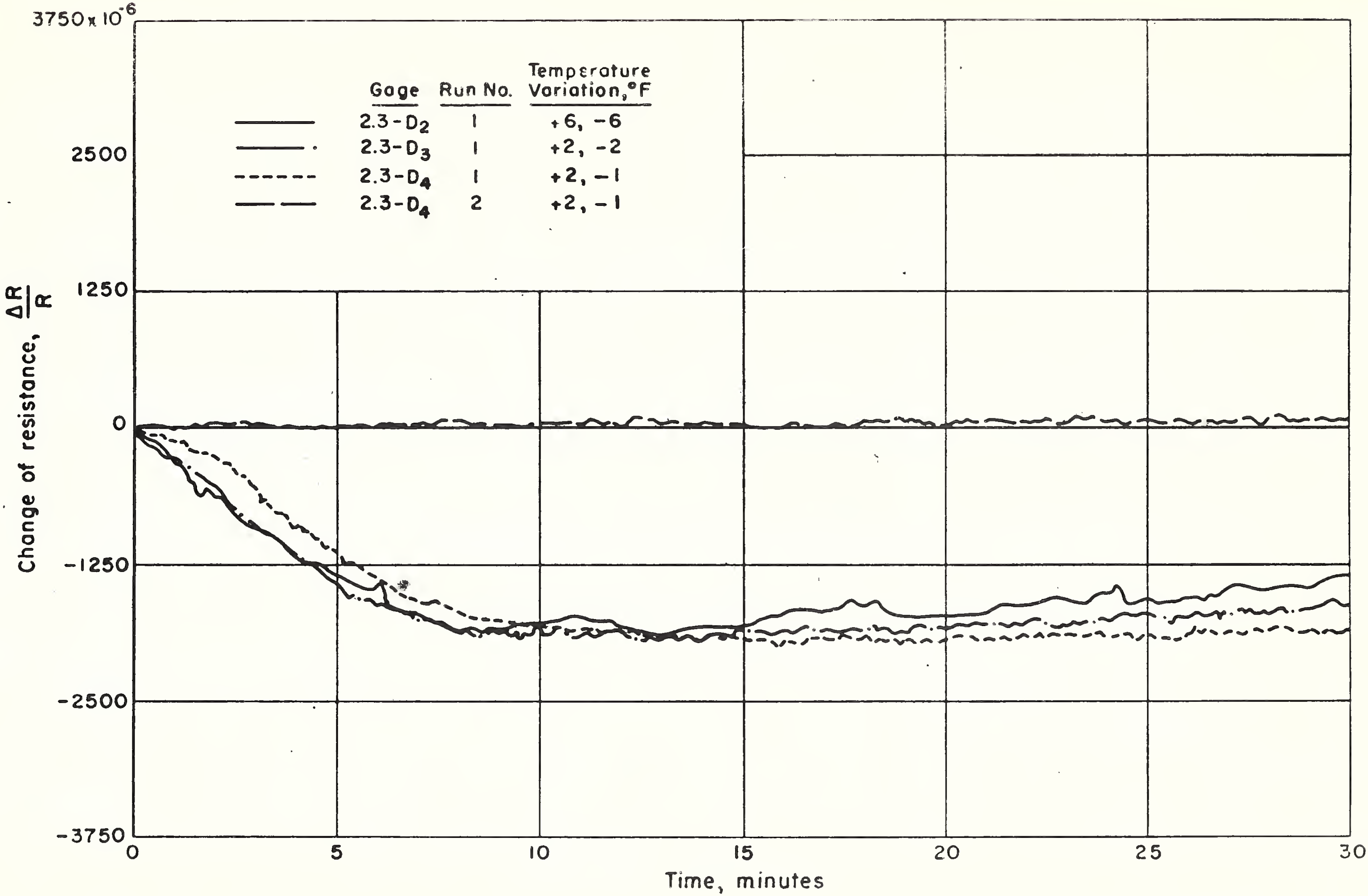


Fig. 17 Drift behavior at 1100°F

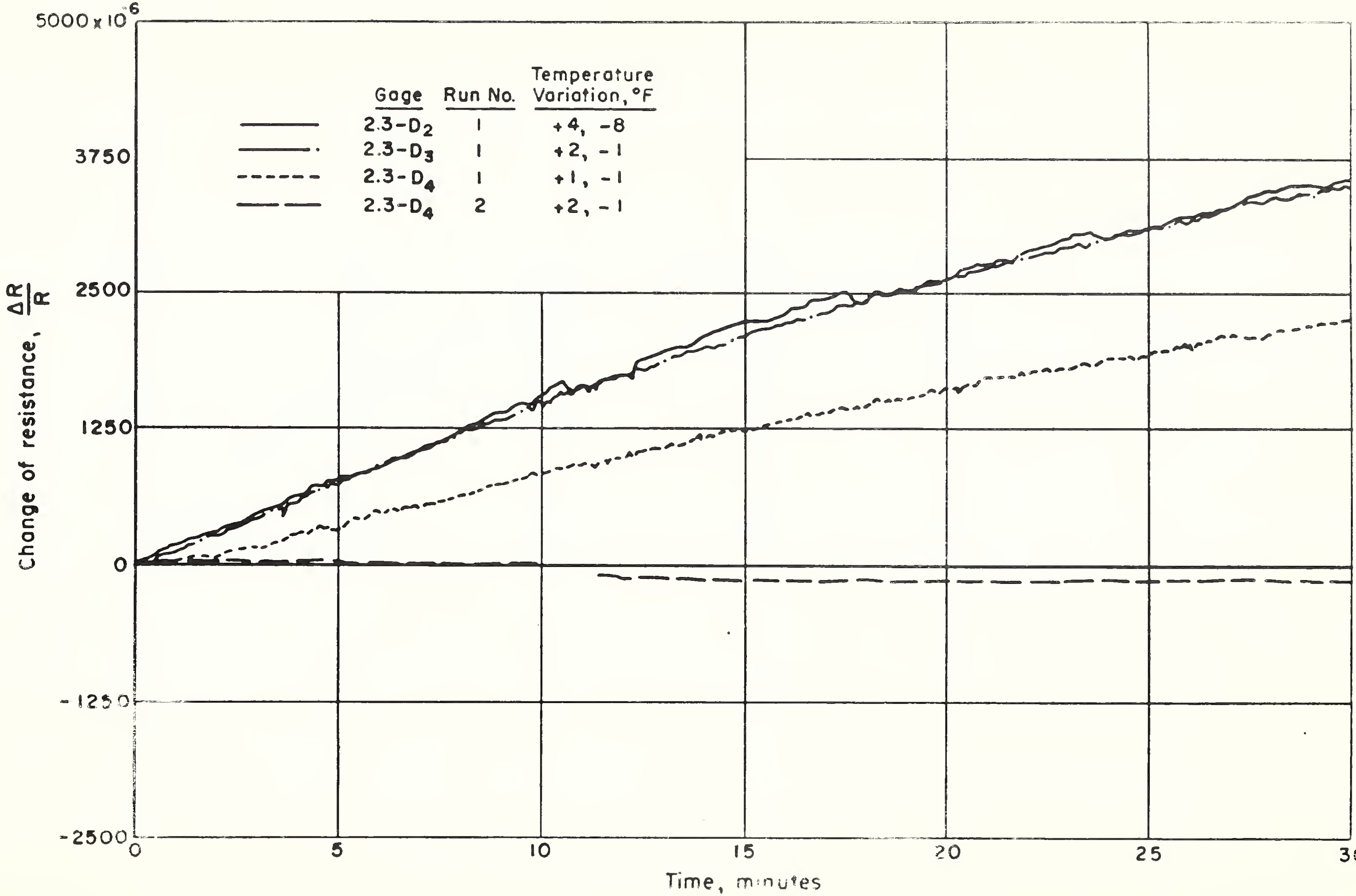


Fig. 18 Drift behavior at 1200° F

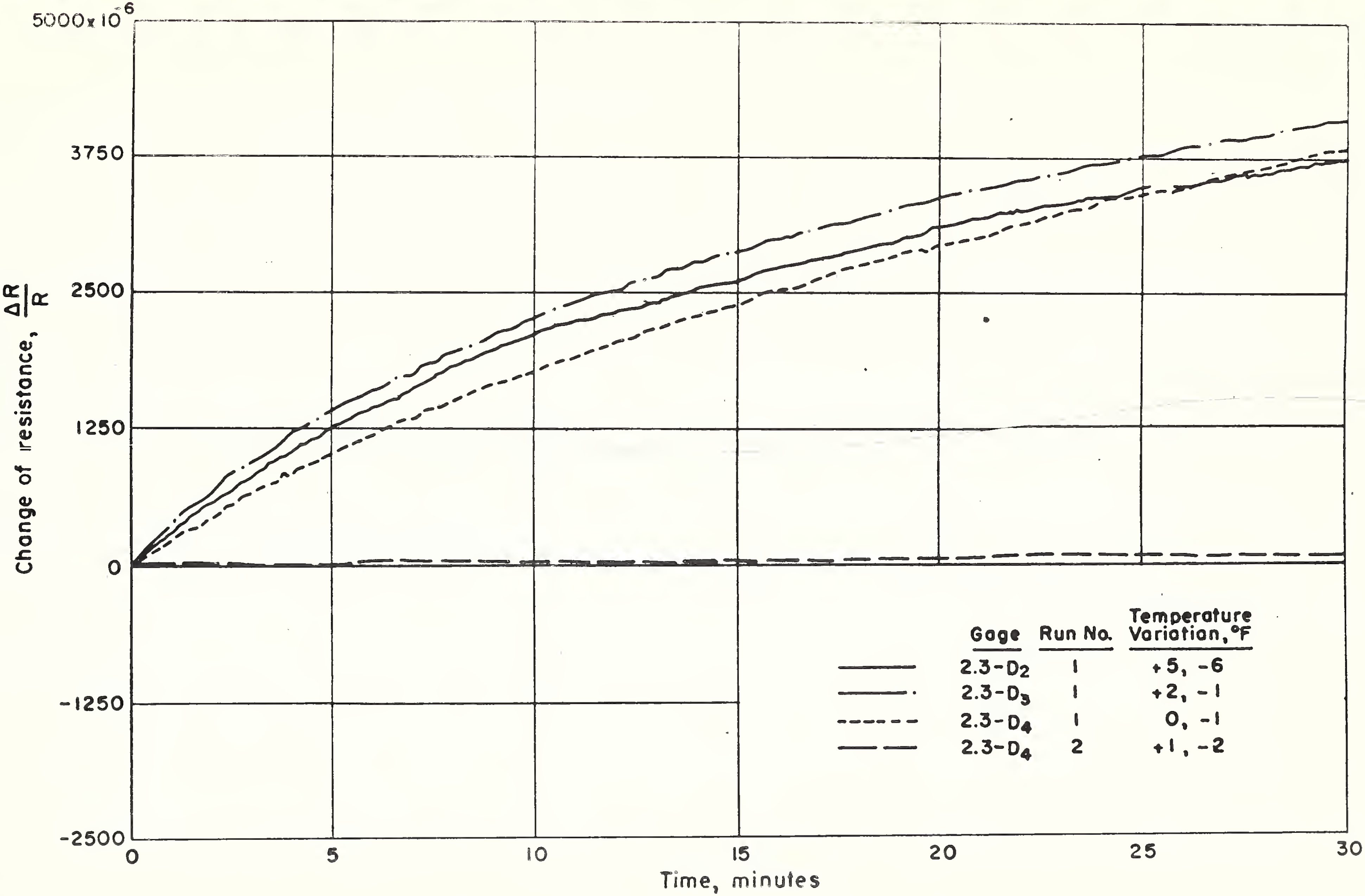
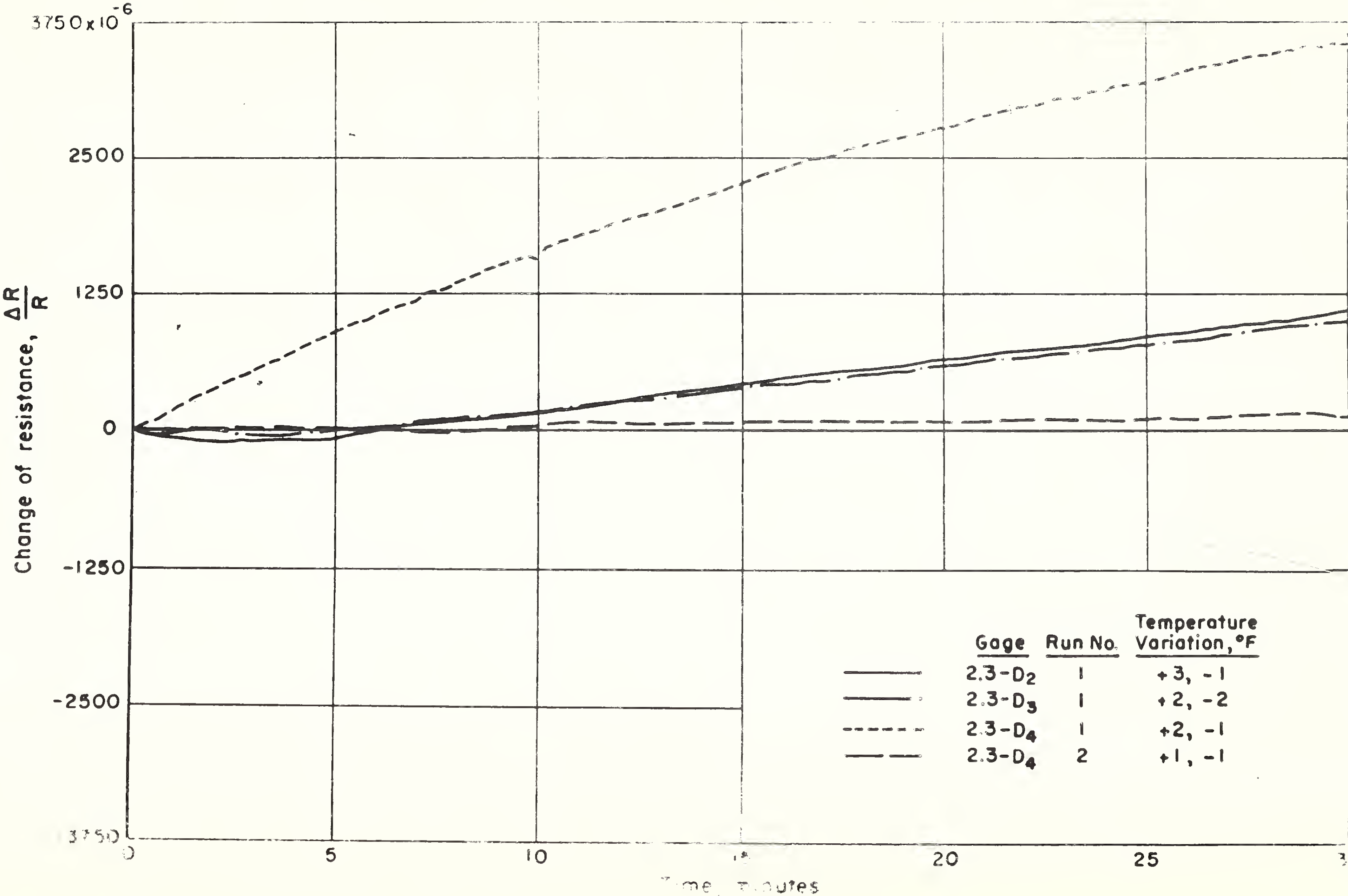


Fig. 19 Drift behavior at 1300° F



g. 20 Drift behavior at 1400°F

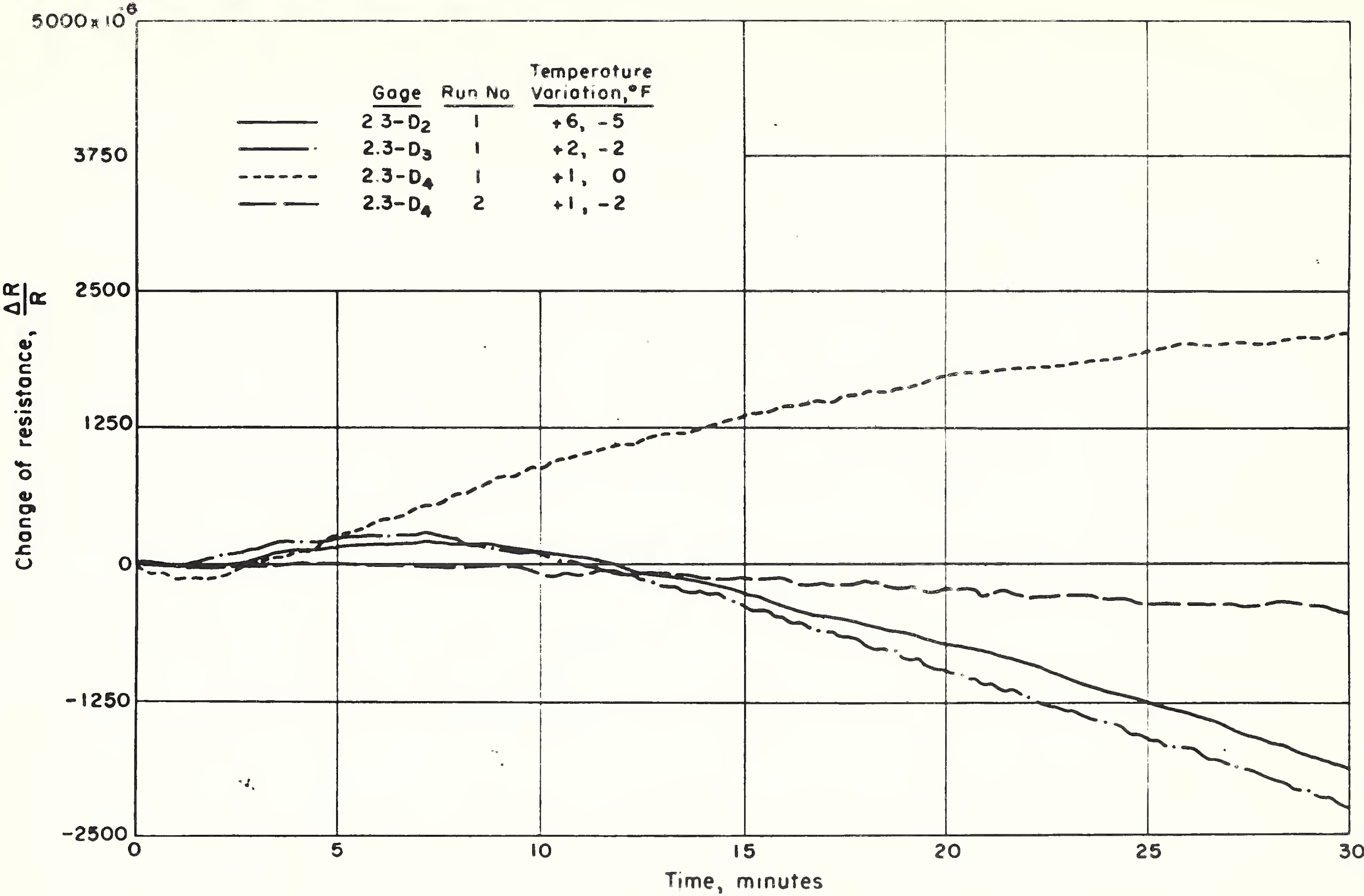


Fig. 21 Drift behavior at 1500° F

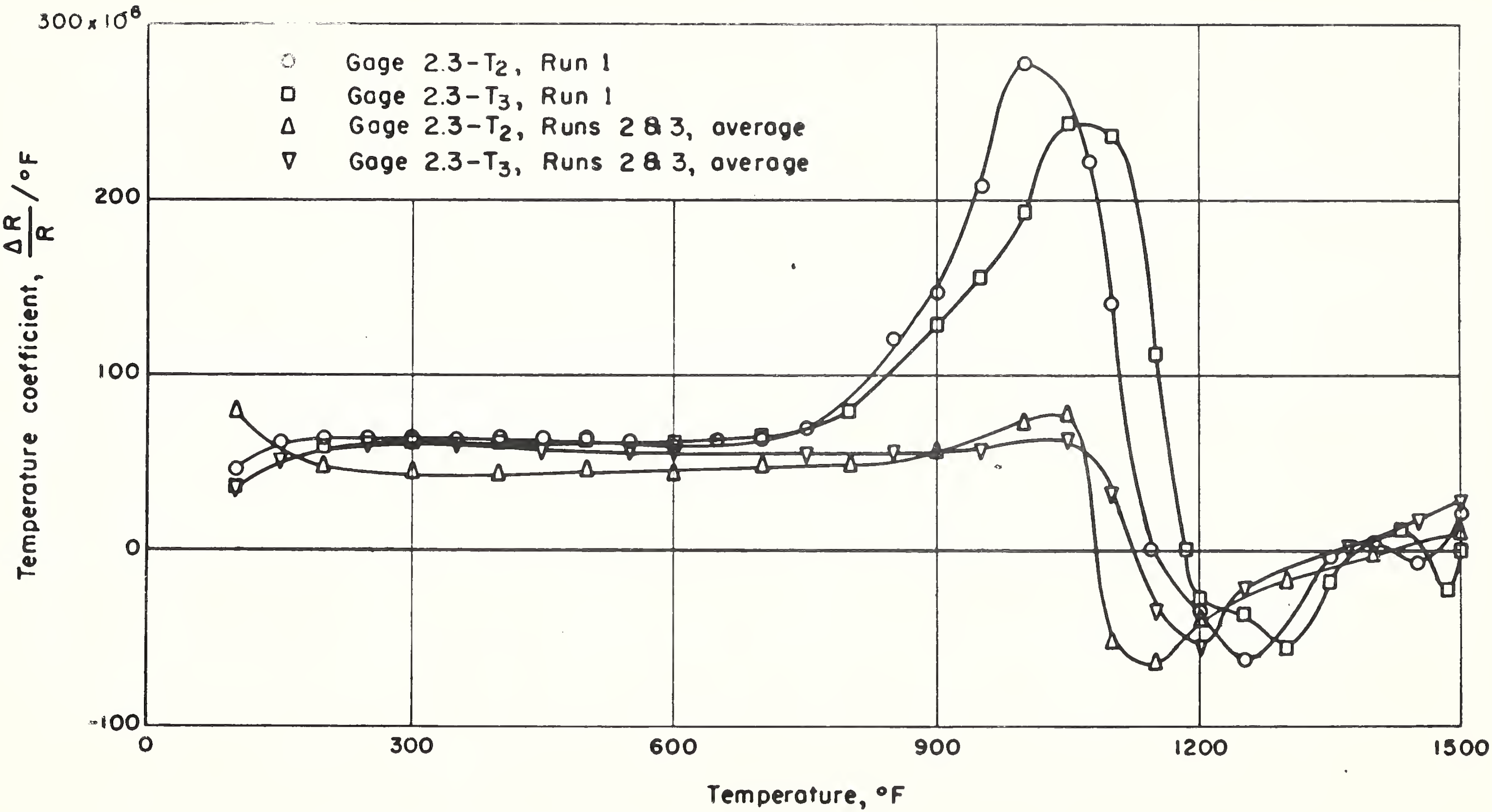


Fig 22 Temperature coefficients for two gages

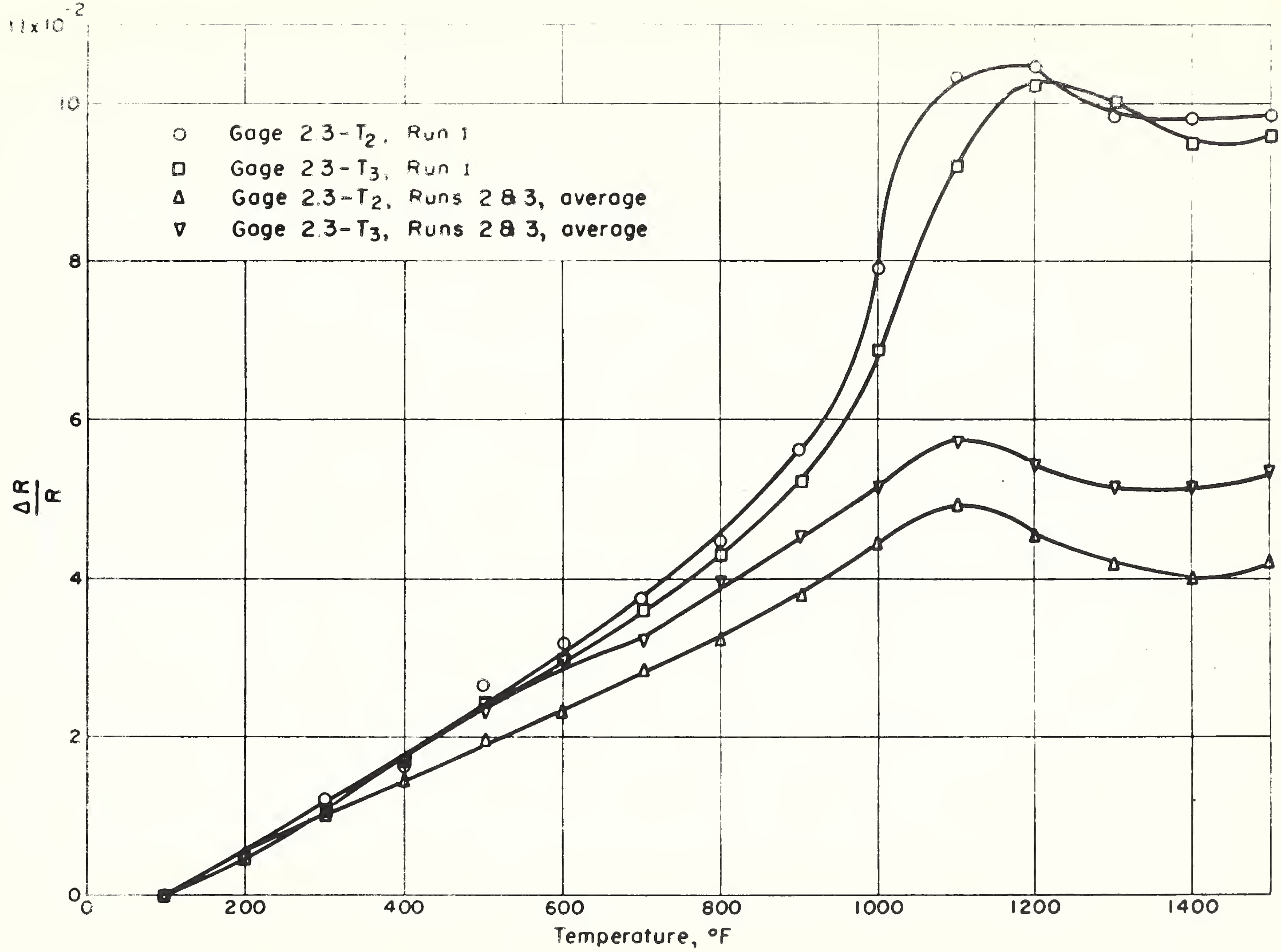


Fig 23 Variation of gage resistance with increasing temperature

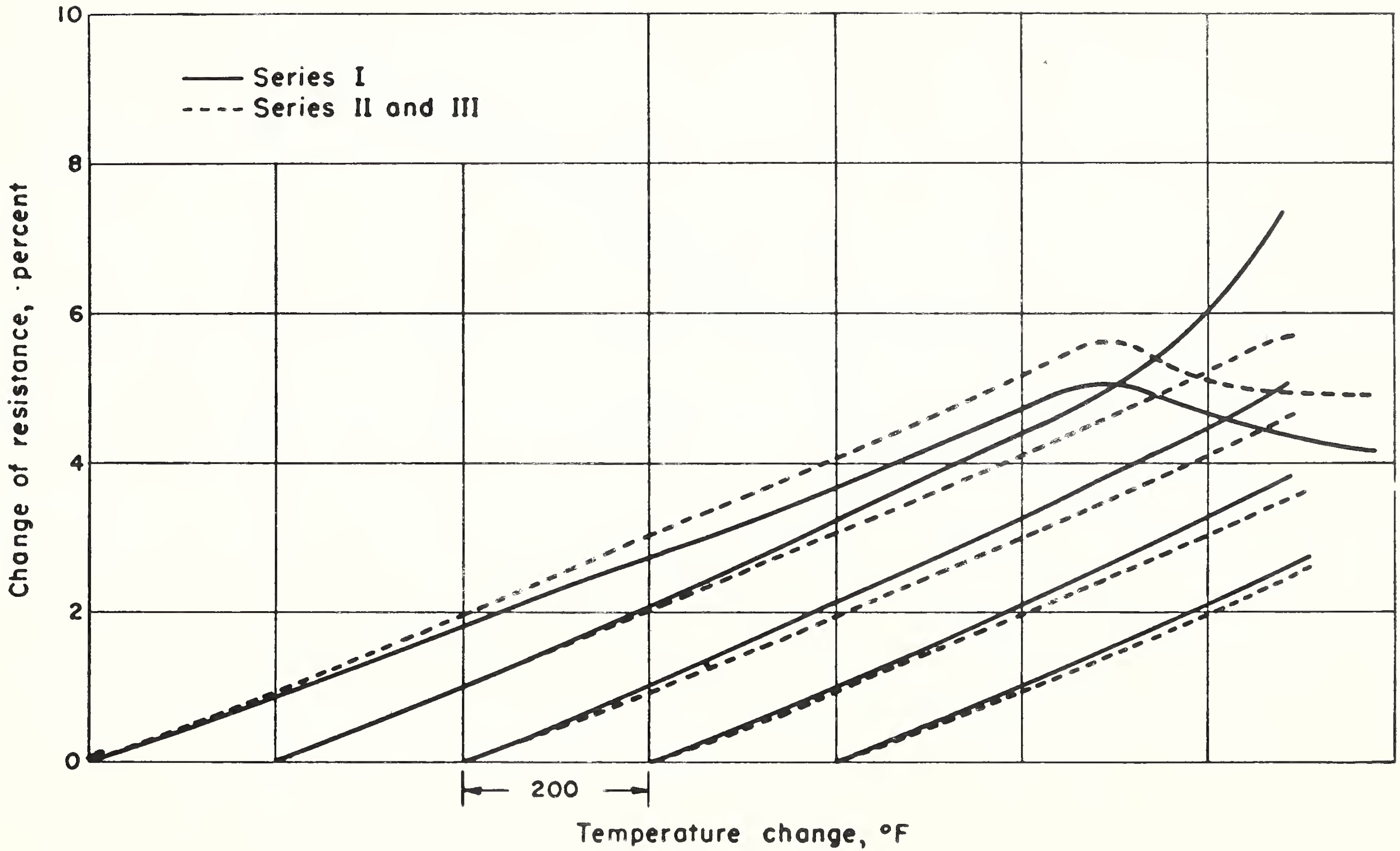


Fig. 24 Response of Gage 2.3-R_1 with transient heating

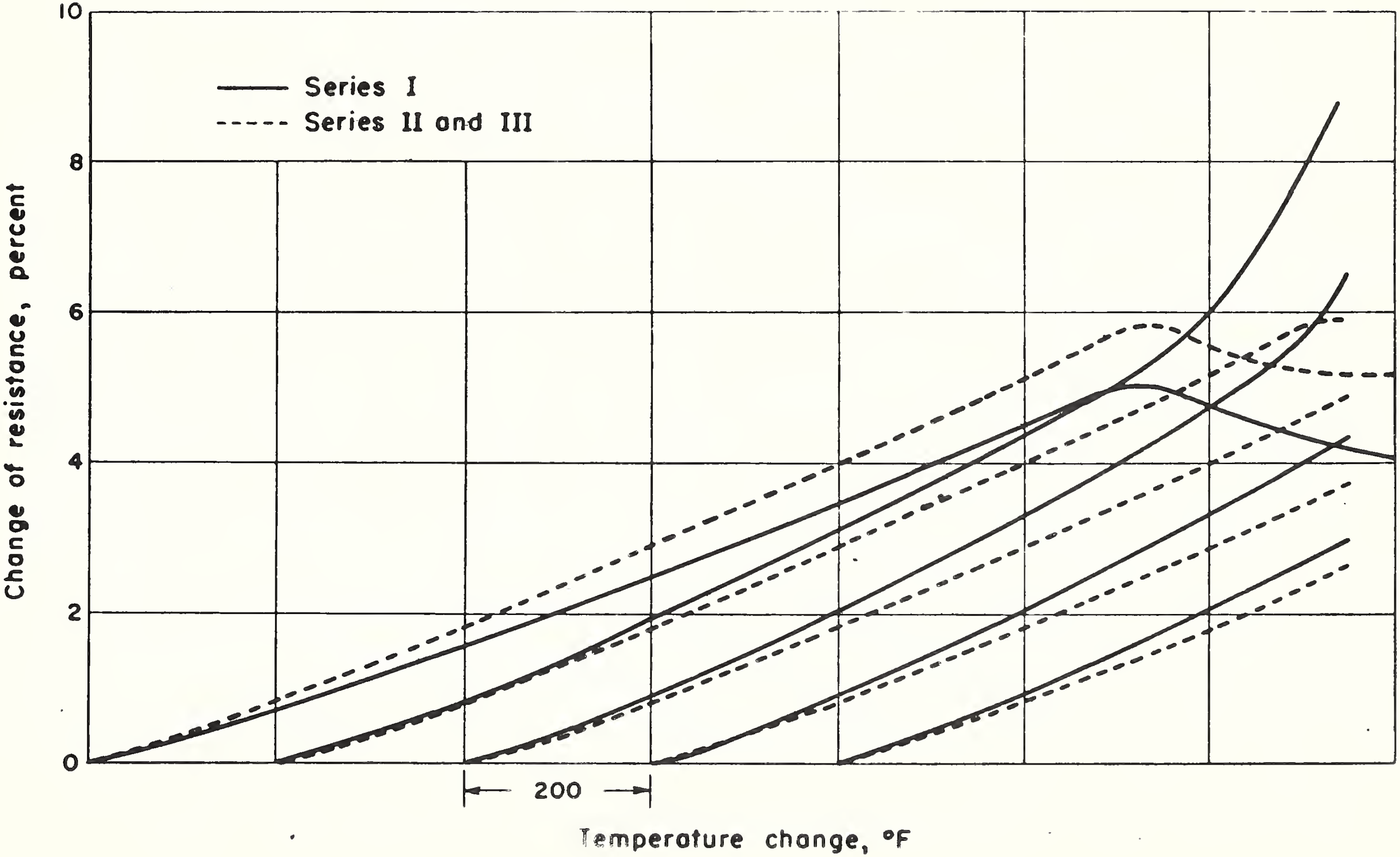


Fig. 25 Response of Gage 2.3 - R_2 with transient heating

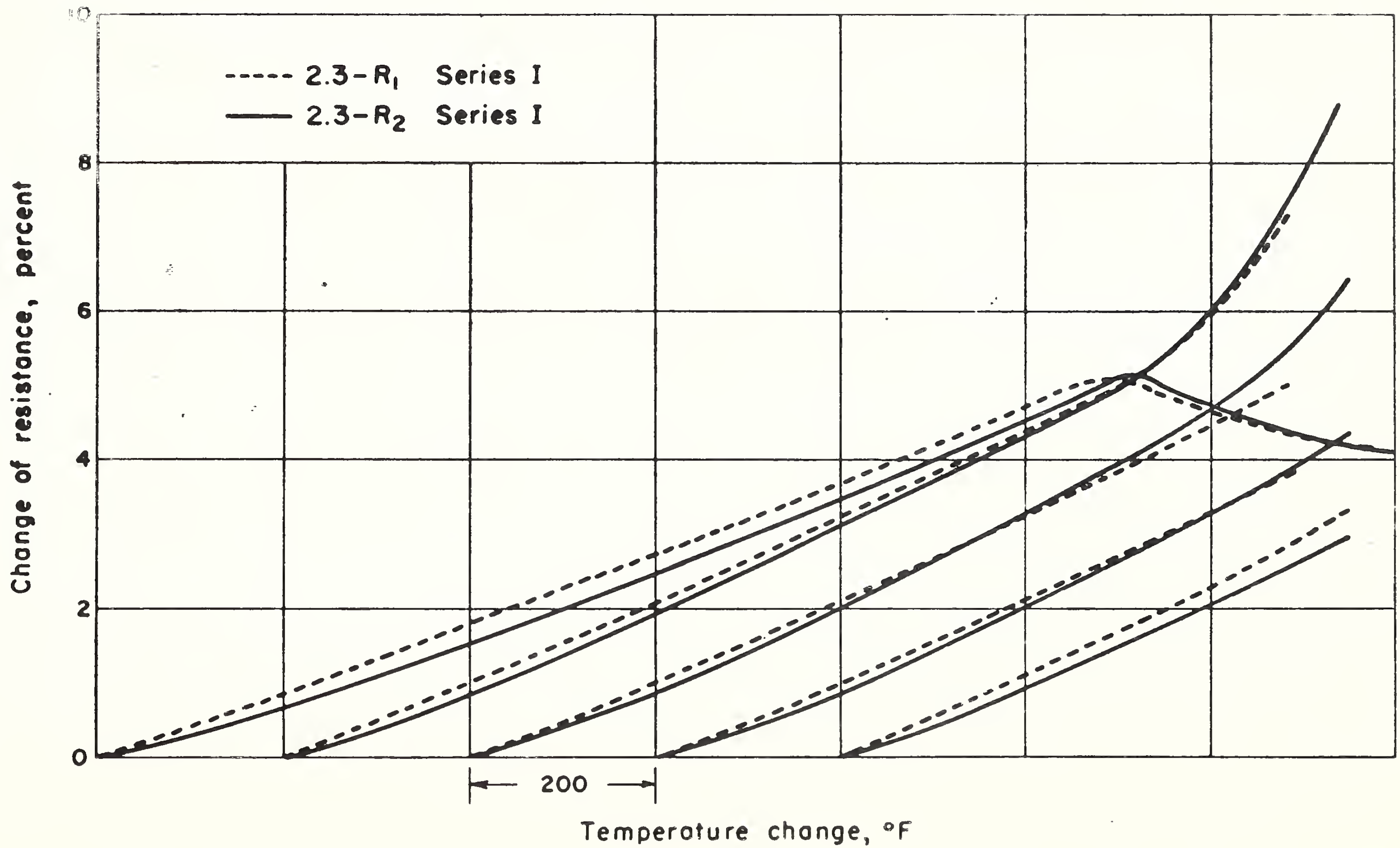


Fig. 26 Response of two gages with transient heating

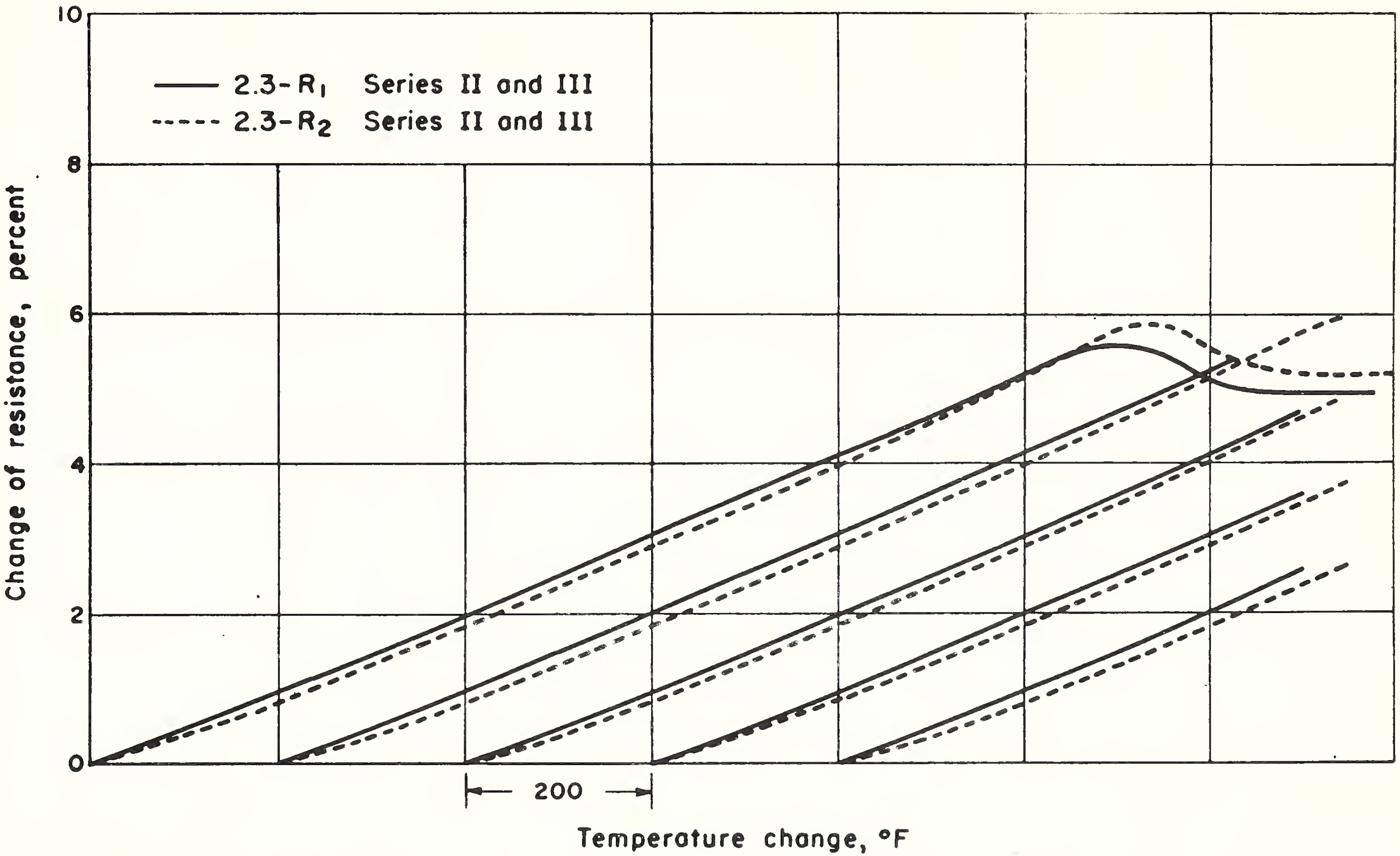


Fig. 27 Response of two gages with transient heating

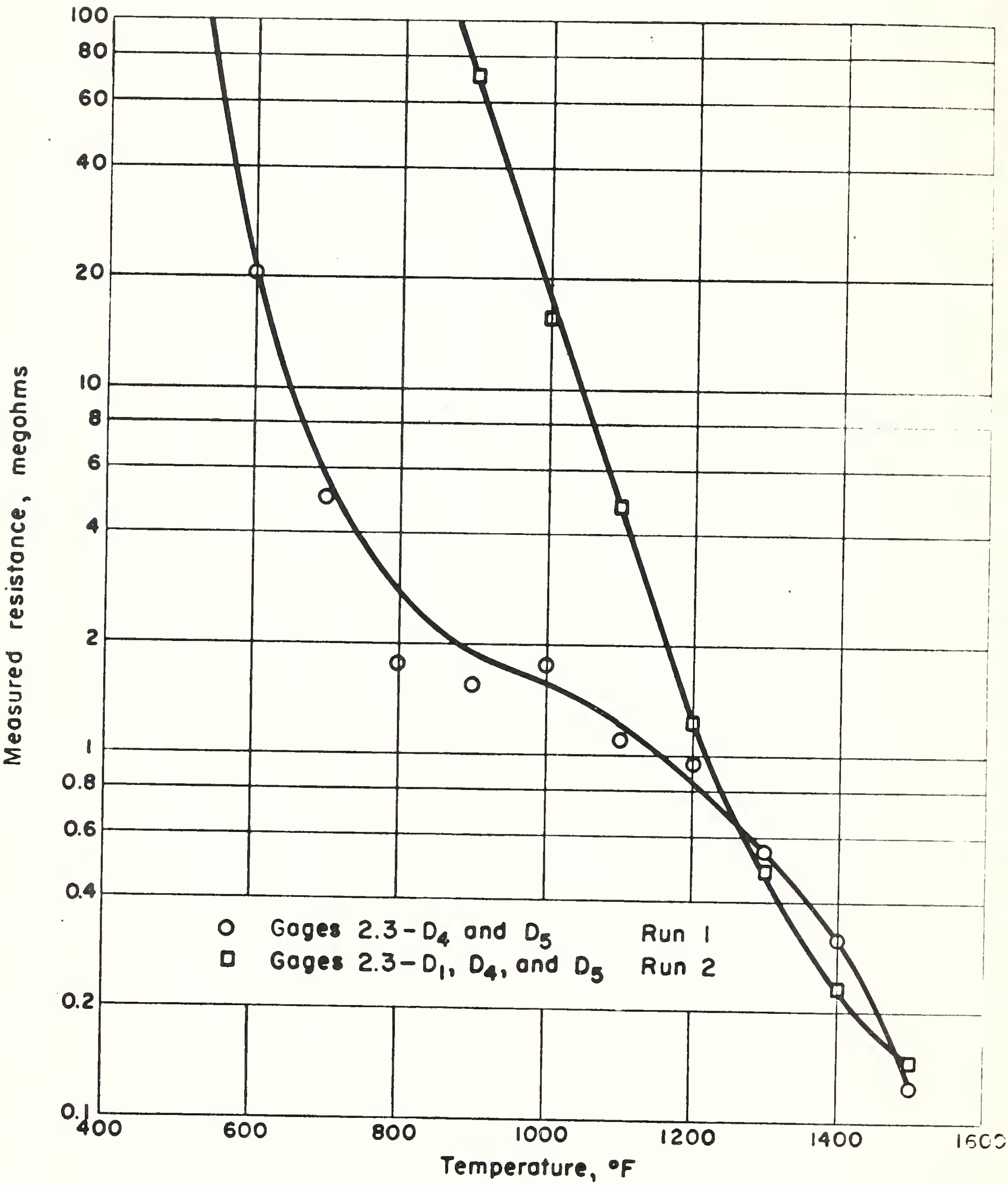


Fig. 28 Average resistance between gage and test strip

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